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STEPHAN BERKO
1924—1991

A Biographical Memoir by

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STEPHAN BERKO

December 16, 1924—May 15, 1991

BY SILVAN S. SCHWEBER

To My Friends

Dear friends, I say friends here
In the larger sense of the word:
Wife, sister, associates, relatives,
Schoolmates, men and women,
Persons seen only once
Or frequented all my life:
Provided that between us, for at least a moment,
Was drawn a segment,
A well defined chord.
I speak for you, companions on a journey
Dense, not devoid of effort,
And also for you who have lost
The soul, the spirit, the wish to live.
Or nobody or somebody, or perhaps only one, or you
Who are reading me: remember the time
Before the wax hardened,
When each of us was like a seal.
Each of us carries the imprint
Of the friend met along the way;
In each the trace of each.
For good or evil
Each stamped by each.
Now that time presses urgently,
And the tasks are finished,
To all of you the modest wish
That the autumn may be long and mild.

Primo Levi, *The Mirror Maker,* 1990, p. 5.

Stephan ("steve") berko was born in Oradea, Rumania, on December 16, 1924. He was raised in Sighet, a small town in the part of northern Transylvania that belonged to Hungary at the time but is now part of Rumania. His father was a physician as had been Steve's grandfather. He did not speak of his mother but spoke often and always admiringly of his father, who had been a talented surgeon, a fine musician, an accomplished skier, and a respected member of the community. He was fluent in several languages and took great pride in his translations into Hungarian of Verlaine and Baudelaire. Steve's maternal grandmother—evidently, a very dynamic and forceful woman—lived with them, and Steve was very close to her. A younger sister, Barbara, was the remaining member of the family. His father had been married before, and Steve had a stepbrother of whom very little is known. The family was fairly well off and lived in a big house that had a large library and a good piano that Steve learned to play at an early age. His parents were Jewish, and although the household was not observant, some religious holidays were celebrated.

A friend who knew Steve in Sighet before the war and who went to school with him relates that he already stood out as a star pupil in elementary school. The war and the adoption of the racial laws changed everything. Steve once indicated that he "had an extremely exciting high school education under rather unpleasant circumstances." During the war, the Jewish High School he attended was in Debrecen. Its faculty consisted for the most part of former university professors who had been dismissed from their posts. He graduated high school in 1943. After graduation he worked as a technical assistant in a small electronics factory in Budapest. Although his father urged him to stay in Budapest after German troops had occupied Hungary, he returned to Sighet. In the spring of 1944 he and his family were taken to Auschwitz. His mother, grandmother, and sister perished there shortly thereafter. Being young and strong he was spared. Like Primo Levi, who arrived in Auschwitz at that same time, Steve was assigned to a “work” *Lager.* He was separated from his father and transferred to a small camp built on top of the ruins of the Warsaw Ghetto to help clean it up. Until a year or so before his death, Steve thought that his father had perished in the gas chambers of Auschwitz shortly after he had been sent to Warsaw.

After the cleanup of the Warsaw Ghetto was completed, Steve was assigned to a labor camp in Dachau. During the winter of 1944-1945, food became exceedingly scarce and facing starvation, prisoners would eat almost anything. Steve ate some berries that made him gravely ill. He almost succumbed and was saved by the ministration of a kindly doctor who hid him from the German guards.

He was the only member of his family to survive.

Steve was liberated from Dachau by American troops shortly after V-E day. He went to Munich, where he found himself without family. He joined a United Nations welfare team that ran one of the largest displaced persons camps in Munich, and at the age of 20 he was put in charge of organizing an entire school system. He spent a year doing that, and he always remembered it as “one of the most rewarding years” of his life. He characterized that experience as being “somewhat similar to—but not identical with the Peace Corps. I had a very, very exciting time and ended up organizing all students who wanted to go to the University of Munich. We organized everything from free trips to the mountains to getting books for them.” He explained that “getting” should be translated as appropriating. By the spring of 1946 the German universities had reopened, and he was a member of the committee of the Jewish Student Union, which he had helped organize, that negotiated with the German government to obtain fellowships for Jewish students to allow them to resume their education. The negotiations were successful and he himself obtained a stipend to attend the Technical University of Munich. He did so starting in the fall of 1946 and became an assistant in mathematics there. Once while reminiscing about the time he spent in Munich, Steve indicated that "in a way these are the two years I am proudest of." It was clearly an exhilarating period in which his freedom was palpably felt every waking minute.

Steve came to the United States in 1947 on a Hillel Foundation Fellowship. These had been underwritten by B'nai B'rith to allow outstanding young people who had survived the concentration camps to obtain a college education in the United Sates. Abram Sachar, who at the time was overseeing the operation of the Hillel Foundation, was in charge of administering the fellowship program. Marie Syrkin, a well-known journalist and one of the editors of *Midstream* and who later became a professor of English at Brandeis University, was sent to Europe to administer the examinations that would decide who was to get the few fellowships that were available. Steve took the test and passed it brilliantly and was one of the first to obtain a fellowship. Later in life he commented that "clearly the Hillel foundation fellowship…played…a phenomenal importance in my life. It actually set my whole direction in life by allowing me to come to the United States."

Steve was sent to the University of Virginia. He had wanted to be either a mathematician or a scientist "from way back," and he started as a mathematics major but soon realized that the subject was too abstract and slowly switched to physics. He obtained a B.A. degree in physics in 1950. As an undergraduate at the University of Virginia, Steve came under the influence of Clinton Joseph Davisson, who had joined the physics department there after retiring from Bell

Laboratories. He "became extremely close to him." Davisson had recognized Steve's abilities and had strongly encouraged him to become an experimenter. Upon obtaining his B.A., Steve decided to stay at Virginia for his doctorate. Three years later he obtained his Ph.D. working under the supervision of Frank L. Hereford.

During the summer of 1950 while working as a research assistant to William Francis Gray Swann at the Bartol Research Foundation in Swarthmore outside Philadelphia, Steve met Ellen Schmidt. They were married after a tumultuous two-week courtship. Ellen was German; her family lived in East Berlin and they were Lutherans. She had been raised by parents who were socialists and who had maintained these views in an environment polarized by fascism. Her charm, her openness, her vivaciousness, and her sense of humor were proof that these qualities could survive in desperate situations of pervasive oppression. For Steve, Ellen probably embodied all that the Munich period had represented: the unburdening that came with the ability to push the past aside, the exhilaration of freedom, the opening of possibilities, and above all, proof that he could love someone and bond to another person. But later, Ellen would also become the victim upon whom Steve would vent his repressed anger—part of the camps' legacies.

When it became clear that he would obtain his Ph.D. in June 1954, Steve had to make a career decision. Did he want to find a position that would allow him to do only research or would he also like to teach? The decision was postponed by a National Research Council Fellowship that took him to Princeton during 1954-1955. He then embarked on a university career by accepting an assistant professorship at his alma mater. In 1958-1959 he went to the Bohr Institute in Copenhagen on a Sloan Foundation Fellowship.

These three awards shaped his intellectual life and his fields of research.

BRANDEIS UNIVERSITY

In 1961 the Department of Physics at Brandeis University, a secular Jewish-sponsored university founded in 1948, was in the process of expanding into experimental physics and was looking for a person to anchor the program and invited Steve to join the department. Steve's reputation had preceded him. The letters of recommendation written on his behalf characterized him as a very imaginative physicist, a superb experimentalist, a fine lecturer, and also noted that he was extremely energetic and mercurial. The letters were accurate. Steve accepted the appointment at Brandeis because of the prospect of being able to build something almost from the beginning. It was also an affirmation of his Jewish roots.

Steve made the Brandeis physics department into a world-renowned center of positron physics. But he did much more than that. He became the chair of the department in 1965, and during the two years of his leadership, the department applied for a National Science Foundation Center of Excellence grant. The application was successful and during his subsequent leadership from 1971 to 1974, Steve oversaw the expansion of the department. He molded the department into one of the best in the United States and helped the university achieve in a very short time its impressive standing in the world of higher education. It would be hard to name another member of the faculty who contributed as much as Steve in helping to make real the founders' vision of what Brandeis was to be. He threw himself into that task wholeheartedly, unstintingly, and selflessly.

Steve became one of the campus's outstanding undergraduate teachers, constantly concerned with the undergraduate curriculum. He was equally concerned with the education of graduate students in physics. A fair fraction of his time was consumed with running the physics department—even when he was not the chair. But his energies were such that he could simultaneously run his laboratory, run the physics department, advise Brandeis's president and its deans, serve on several faculty committees and on the Faculty Senate, and be the faculty representative to the Board of Trustees.

His efforts did not go unrewarded. He earned the respect of his colleagues. His accomplishments as a physicist were recognized by the numerous lecture invitations he received from all over the world, and was capped by his election to the National Academy of Sciences in 1988. He derived enormous satisfaction from the inspiring *Festspiel* his students organized in 1984 for his 60th birthday. On that occasion his admirers filled the large lecture room. Over 30 of his Ph.D. students came back to express their affection, gratitude, and respect. Among them were to be found some of the best experimentalists of their generation.

CHARACTER

There are many ways Holocaust survivors deal with their overwhelming experience. One is to shut off feelings, to seal off the realm of the emotions, and to come to terms with the world coldly, calculatingly, with detachment, by taking personal responsibility for all actions, and not allowing the outside to upset whatever inner equilibrium they had achieved. Another is to expose themselves and to make the external onslaughts keep them whole as best they can: it is so to say the very buffeting that creates the pressure that keeps the lid on, that gives their lives some stability. Both are attempts to adapt to one of the indelible consequences of the camp experience: the destruction of the ability to live with oneself in a community; and this because the concentration camps took from the survivors their belief in human solidarity.

These are extreme versions and there is probably a correlation between the mechanism adopted and the length of time spent in camps. The usual response is some combination of the two. Steve was very much in the second group. He needed to be “a big fish in a small pond”—his words—not because he wanted to be at the top of the pecking order but because under these circumstances the density and frequency of interactions would keep him whole much better than being a small fish in a big pond. He was always a presence in any meeting; some people perceived him as domineering. He needed the interactions to keep himself together. He needed to challenge, because one of the essential lessons he had learned was that you cannot allow any authority to go unchallenged.

Steve’s past was ever present. One of his students recalled attending an international conference with him. At one of the coffee breaks the two of them were standing with a group of people who were swapping stories. When one of the scientists began to talk with a heavy German accent, Steve became visibly ill and moved away from the group as quickly as possible. His student went with him not knowing what was wrong. Steve confided that at that moment “simply hearing the accent brought to mind some of the horrors he had experienced.” A sense of extreme vulnerability and fragility must surely be one of the legacies of being a survivor. It should therefore not be surprising that a proclivity for mistrust and suspicion should become character traits of such people. The legacy of the camp experience was perhaps most visible in Steve’s interactions with his colleagues. Steve’s capacity for distrust was almost without bound. Relations with his colleagues in the department were often rocky, always tainted by distrust. One of his students tells that when a visit from a fellow positron scientist was expected, they were instructed to hide any notes, drawings, or anything that hinted of current projects.

In some cases they were even instructed to leave deceptive notes about. All the students working in Steve's laboratory had a difficult time with him. They invariably feared him at first. The most perceptive of them recognized that the strains for the most part were the result of his inability to express overtly his deep affection and care for those under his wing. The meetings between Steve and his research group would at times be painful affairs. Inevitably either an undergraduate, or a graduate student, or a postdoc would be singled out and be unmistakably reminded of his stupidity, incompetence, sloth, or lack of imagination. Afterward Steve would be contrite. The obverse side of these interactions was that behind the scenes Steve would do anything in his power to insure his students' continued participation in the research activities of his laboratory. Steve would pull any strings within his grasp to see that a critical course was passed should the student have done poorly in it, that some peculiar financial aid was created if he had insufficient funds in his grants to cover the student's financial needs, or that a visa was renewed should the student be a foreigner.

Steve had a very hard time living with himself and therefore others had a hard time living with him. He was a difficult person, yet everyone who came to know him was aware that whatever he did, the well-being of others and that of his community always came before his own.

Steve was a remarkable man, remarkable in his gifts and talents, remarkable in his achievements, but perhaps most remarkable in having given so much of himself even though so much had been taken from him.

He had a greater affinity for music and the visual arts than for literature. He took enormous delight in visiting museums and in going to concerts. Characteristically these proclivities manifested themselves most conspicuously in his friendships. Two of his closest friends at Brandeis were the composer Seymour Schiffrin and the art historian Bill Seitz. Isaac Bashevis Singer once noted that the war between the emotions and the intellect is the very essence of literature. Perhaps because that conflict was always raging within Steve, he was more drawn to paintings and music. He was very proud of his hi-fi equipment and he owned a large collection of recordings of operatic, chamber, and orchestral music. He would play his disks at full volume, thus simultaneously shutting out the rest of the world and fusing intellect and emotion. His cultivation of the arts was not passive. He was a superb photographer with a fine eye for the dramatic and a flair for composition and color, again melding intellect and emotion. He was a competent pianist but he could not find the time, or perhaps did not have the patience, to realize his talents and ambitions as a performer. Steve went to the movies regularly; they clearly brought him relaxation, enjoyment, and catharsis. He would thereafter collar his friends urging them to go see the ones he liked. Two movies he was particularly fond of were *The Unbearable Lightness of Being and Friends* and *Enemies: A Love Story.*

Although I have stressed Steve's propensity for the arts and music, it is Italo Calvino—a fellow traveler on that dense journey "not devoid of effort"—who in his reflections on literature captured most succinctly some of Steve's qualities. His were the content of the six Norton lectures Calvino was to deliver at Harvard in 1985. Their titles were 1-Lightness, 2-Quickness, 3-Exactitude, 4-Visibility, 5-Multiplicity, and 6-Consistency. The last lecture was never written. Calvino died of a brain hemorrhage before writing it. Each of the lectures discusses a quality Calvino prized in his own work and that of others. Each of these is also to be found in Steve and his works. Milan Kundera's *The Unbearable Lightness of Being* is the book that for Calvino best captured what he meant by lightness. He saw the novel as "a bitter confirmation of the Ineluctable Weight of Living" not only in situations of desperate and pervading oppression but also in the human condition in general. Steve's puns articulated that same unbearable lightness of being in the face of the terrible psychic and physical pain that was his constant condition. Puns were an expression of the fierce pride with which he pursued excellence, and hardly a day passed when you were not treated to one. No physics faculty meeting ever took place without several displays of Steve's punning prowess.

Let me illustrate his mastery of that subtle art with two revealing examples. In the mid-1980s, partially out of embarrassment induced by his daughters' continued prodding, Steve went out and bought his wife a lovely new car. Shortly afterward the car began emitting exhaust fumes so noxious that they had to leave the car in the driveway because when garaged it made the house uninhabitable. During this same period, his youngest daughter was dating a nice young man from a Catholic family. Steve was quite ecumenical in his approach to religion, but it was apparent to him that if they married, the demands of the young man's family would almost certainly eliminate all vestiges of Judaism from their lives. This clearly grated on Steve's spirit. Reflecting on the state of his affairs, Steve commented, "Nearly all the problems of my life are due to faulty Catholic Conversion."

Invariably, every fall one the topics of conversation in Steve's positron group would be about who was to receive the Nobel Prize in Physics that year. And every year the following scene would be repeated: After some discussion about the leading contenders for the prize, Steve would place his hands on his ample midriff and state that he was not worried because he was a strong contender for the "no-belly" prize. Even though he would then laugh, his laugh also concealed a sigh. For Steve was very ambitious; he knew his powers and drove himself relentlessly.

Steve was always delighted by his puns. They were uttered at any time and at any place if something was said that somehow triggered his punning faculty. They reflected his quickness, a quality that Calvino valued: "thinking means quickness, agility in reasoning, economy in argument but also the use of imaginative examples."

In his lecture on exactitude Calvino described it as "a well defined and well calculated plan for the work in question; an evocation of clear, incisive, memorable visual images and a language as precise as possible both in choice of words and in expression of subtleties and imagination." In his writings, discussions, and presentations Steve always displayed exactitude. When analyzing "visibility," Calvino distinguished between two types of imaginative processes: "the one that starts with the word and arrives at visual images and the one that starts with the visual image and arrives at its verbal expression." The second was more characteristic of Steve.

Steve had problems coming to terms with consistency; he had difficulty with finding the means to make his life consistent and coherent. Being compulsively busy was one of the mechanisms that helped Steve get through each day. The pursuit of knowledge, in particular of science, the knowledge of nature, and devotion and commitment to an institution became means to secure consistency on a longer time scale. Physics became his religion, the path to transcendence, the university his church, his path to morality. He was a bishop in that church, with the department of physics his see. Canon law defines the responsibility of bishops as "teachers of doctrine, priests of sacred worship, and ministers of governance." Like a bishop he was the principal authority within his see. In fact, he achieved the status of cardinal both within the university and within the physics community, as attested by his constant presence in the inner councils of the university membership and his election to the National Academy of Sciences in 1988.

THE LAST YEARS

For over four decades Steve pursued his academic vocation with success and single-mindedness. Writing scientific papers, educating liberal arts majors, producing bachelors of science and doctors of philosophy, and building Brandeis gave cohesion and consistency to his life. Physics and Brandeis were the sinews of his integrity. But periodically this vocation failed to absorb his enormous energies, and he would succumb to fits of deep depression. During the 1980s when Brandeis fell on hard times and some of its basic tenets were being challenged by the administration, Steve was particularly despondent.

Despite the public recognition that Steve received, his last years were not easy. The necessity to run ever faster on the treadmill to do cutting-edge research took its toll. Although he derived great satisfaction from still being able to make important and original contributions to the field of high-temperature superconductivity—then one of the most competitive research areas in condensed matter physics—the price for doing so was very high and at times he doubted that it was worth the candle. Throughout Steve's life the cost of the running was inflated by the fact that he was afflicted with ever present, severe back pains and a constant tinnitus, legacies of the time spent in Auschwitz and Dachau. Over the years the back condition deteriorated and an extensive operation failed to relieve the pain. The gravity of the situation and Steve's courage were demonstrated by his willingness to undergo a second major operation to relieve the condition a few months before his death.

Steve also became deeply affected by the courageous battle that his colleague and friend Eugene Gross waged against pancreatic cancer, and by his death in January 1991. But more troubling than Gene's illness were the facts he had learned about his father's death in Auschwitz during a visit to his hometown in Hungary in 1989. His father had not died in the gas chambers of Auschwitz but as the result of a beating from fellow prisoners. The Nazis' destruction of human solidarity had indeed been complete. The death of his father haunted him day and night thereafter and reified the nightmare of his youth. Steve talked of his despondency but also expressed confidence that it would pass. Indeed, he had enormous resilience. Moreover, he felt that there were positive aspects to the situation; he had confronted himself and the future and had come to some conclusions on how he would like to live the finite amount of time ahead of him. He had made certain important decisions and was looking forward to the new lifestyle he was designing.

During the last years of his life, he and I talked about many things during our encounters but two themes recurred in every one of them. One was the enormous pride he took in his daughters. "Ellen and I must have done something right," he would say. He delighted in their accomplishments, familial and professional, and gave himself some credit for the fact that each one of them had married unusually fine human beings. The other theme was how good his marriage to Ellen had become.

But by a strange twist of the logic under which he operated—namely, precisely because he felt that the future of his daughters was secure, that Brandeis' future looked more hopeful with its new president—looking ahead to retirement became ever more problematic. He was also apprehensive about the loss of his intellectual and physical faculties with advancing age and the consequent loss of control of those aspects of his life that were most meaningful to him.

At the end, success no longer seemed compelling, and he began obsessively to ask himself what his existence had really meant. And here the legacy of the devastation of the Holocaust took its ultimate toll: neither family nor friends could convince him—nor could he himself—either of the magnitude of his past accomplishments or the inestimable value of his presence.

He took his own life and died prematurely, a casualty of the unprecedented acts of inhumanity that were carried out during World War II. He paid a heavy price for these during his life but perhaps none greater than the few years he so yearned for to enjoy with his wife, his children, and grandchildren.

Steve had much in common with Primo Levi. Both were emancipated Jews; both were at Auschwitz; both were scientists; both gave up at the end of their lives and took their own lives. They differed in that Primo Levi constantly sought to come to terms with the concentration camps through his writings. Steve shunned entering into a dialogue about his camp experiences. But both had concluded that the meaning of the camps was to be found in man.

Both Levi and Steve had abandoned God. Both focused their energies on man. Levi through his writing, Steve through his involvement with his family, his students, and the institutions he belonged to. Levi sought to understand the Shoah in terms of what it reveals about man. Berko sought to redeem it through what he could do for man. For both of them the Holocaust had meaning, and could be understood in rational terms. Levi spent his last decades trying to understand the German context, trying to understand what allowed the Shoah to happen, what made it possible for Germans to see Jews as subhuman and their programmed extermination as an issue in racial hygiene.

And by focusing on man, by considering God irrelevant, they could manage to walk the tightrope that survival demanded. They committed themselves to certain universals that they took to be absolutes for membership in the human species. These were that the dignity of personhood was irreducible and that a human life was invaluable and deserved a respect that nothing could undermine.

Our lives were jarred and were enriched by them. They indicated to us the heights that human beings can scale even while carrying the burden of the legacy of the depths of cruelty to which human beings can sink.

With Steve's untimely death Brandeis University, the physics community, and the National Academy of Sciences lost a member of outstanding distinction.

THE TEACHER

Berko was an outstanding physicist, an unusually gifted experimentalist, an exceptional teacher, and an inspired mentor. All these qualities found their expression in physics. Berko was a masterful lecturer. In his teaching duties he devoted considerable efforts to the introductory course for physics majors. He designed and constructed a large number of demonstrations for his lectures, and also met interested students in weekly special classes devoted to more detailed presentations of the lecture materials or to more advanced topics. Similarly, for many years he took charge of the advanced undergraduate experimental laboratory courses and the graduate experimental laboratory course. In them he introduced students to a large number of apparatuses and a wide variety of techniques, and gave them hands-on experience in their uses; he also designed many new experiments covering a variety of fields of physics for these courses. He supervised many senior theses in experimental physics. The results of one set of them, on laser diffraction experiments using large objects, were published in the *American Journal of Physics* (1970.) At the invitation of Jerrold Zacharias, chair of the Physical Science Study Committee (PSSC), Berko made two demonstration movies for college-level teaching: "Electron-Positron Annihilation" (1970) and "Single Photon Polarization," which are still available.

As difficult as he might have been at times Berko was a mentor to all his Ph.D. students. His commitment and devotion to research, his stubborn need to understand as fully as possible the meaning of experimental data, his uncompromising integrity, his passionate sense of justice and responsibility, his intensely felt care and caring, and his enduring, unstinting help was recognized and deeply appreciated by all his students. Conversely, Berko recognized that his students' help, commitment, and hard work were essential factors in his successful research efforts. Most of his experimental papers were coauthored with students. Page vii of the proceedings of the 1984 symposium celebrating his accomplishments (Mills et al., 1986) on the occasion of his 60th birthday is devoted to a group photograph of the participants, among whom were his 18 Ph.D. students up to that time, and a large number of the postdocs who had come to work in his laboratory. Berko was rather restrained as far as physical contact was concerned. But in this picture a proud and almost beaming Berko stands with his left hand on the shoulder of Allan Mills, one of his outstanding students, who became his colleague and collaborator.

THE PHYSICIST

Berko's research for his Ph.D. was an investigation of the deflection of cosmic-ray mu-mesons and high-energy electrons in magnetized iron. To interpret the result of his measurements he mastered the modern quantum mechanical theory of ferromagnetism and contributed to the theory of multiple scattering of high-energy particles in solids. He demonstrated that the appropriate phenomenological interpretation of the data he had collected is that in a ferromagnetic solid the magnetic induction ***B*** is responsible for the deflection and not the magnetic field ***H***. The content of his thesis found expression in a review of experiments on the ferromagnetic deflection of mu-mesons and electrons that Berko wrote with Hereford (1954). That article won the Sheldon-Hosley Award of the Virginia Academy of Science.

It was as a postdoctoral fellow in Princeton in 1953-1954 that Berko was introduced to positrons and positronium by interacting with Robert Dicke. In 1951 Martin Deutsch at MIT had established the existence and properties of positronium (Ps), the quasi-stable bound system of an electron and its antiparticle, the positron. Positronium—as the simplest leptonic purely electromagnetically bound state—constitutes an ideal system for which the results of applying the calculational algorithms and the renormalization procedures that Feynman, Schwinger, and Dyson formulated for obtaining finite, meaningful results in quantum electrodynamics can be compared with experimental data. It is also an ideal system for studying the description of bound state in quantum field theory and in quantum electrodynamics (QED) in particular.

Despite Ps's short lifetime against annihilation (10^{-10} sec) experimental techniques developed during World War II made it possible to ascertain many of its structural properties. Thus by 1954 Weinstein, Deutsch, and Brown (1953) at MIT and Pond and Dicke (1954) at Princeton had measured the fine structure splitting of the positronium ground state to an accuracy of five significant figures. Their experimental results agreed with the quantum electrodynamic calculations to order α^5. Dicke had devised many of the early electronic circuits to measure accurately and precisely short time intervals, and Berko learned the art and science of their design as a postdoctoral fellow at Princeton during the academic year 1953-1954.

When Berko returned to the University of Virginia as a faculty member in the fall of 1954 he developed two separate research programs: (1) the study of medium-energy neutron scattering from nuclei to test the nuclear optical model, using a small Van de Graaf accelerator; and (2) the development of positron annihilation as a tool in solid-state physics. Although these two research areas seem distant from each other, they do have a very close underlying theoretical basis: the use of external probes to study the structural properties of many-body systems.

While a Sloan fellow at the University of Copenhagen in 1957-1958, Berko initiated there experiments on the Coulomb excitation of heavy nuclei, using protons accelerated in the Niels Bohr Institute cyclotron. It was his last major effort in experimental nuclear physics.

Berko's seminal contributions and most of his researches dealt with positron-matter interactions and with the structural properties of positronium. These researches continued till the end of his life. The first such experiments explored the influence of the environment on positronium lifetimes, in particular, the effects of chemical composition and those of temperature. Berko's subsequent researches on the interaction of positronium with free radicals and the study of positronium in molecular substances led to development of a new field, positronium chemistry.

While performing experiments that dealt with positronium chemistry, Berko constructed the apparatus to carry out very precise and accurate measurements of the angular correlation of the annihilation radiation (ACAR) of positrons in solids. In 1957 with J. S. Plaskett and R. E. Kelley, Berko published his first ACAR paper, which reported a large anisotropy in graphite. In 1958 Berko with Plaskett published a paper entitled “Correlation of Annihilation Radiation in Oriented Single Metal Crystals,” which has been characterized as “truly seminal.” S. DeBenedetti and A. T. Stewart had earlier published results indicating the value of ACAR measurements in determining structural properties of polycrystalline solids. Berko and Plaskett computed for the first time a realistic positron wave function in metals, discussed the information that could be obtained from such ACAR experiments regarding the band structure of metals, and stressed the usefulness and efficacy of looking at anisotropies in the angular correlations of the annihilation radiation in oriented single crystals in order to study the Fermi surface of metals. Their formulation provided the foundation for much of the subsequent work on oriented single crystals.

It is indicative of Berko’s mastery of both the experimental and theoretical aspects of positron and positronium physics that by 1956 he published a long article in the *Reviews of Modern Physics,* written with Frank Hereford, entitled ”Experimental Studies of Positron Interactions in Solids and Liquids.” The article summarized all that was known in the field up to that time. Though called experimental studies, it also presented a critical exposition of recent theoretical studies elucidating experimental results. The review contained a thorough presentation of the questions that could be answered regarding the electronic structure of gases, liquids, and solids by using positrons; and it illustrated the answers by detailing and explaining the results obtained in specific cases. This initial article became the model for Berko’s later reviews of the field, the last of which, entitled “Momentum Density and Fermi-Surface Measurements in Metals by Positron Annihilation” (1983) was the content of his 1981 Varenna lectures at the International School of Physics “Enrico Fermi.”

In the 1981 Varenna lectures, as had been the case in the 1956 *Reviews of Modern Physics article,* Berko gave an overview of the "present" physical picture of the behavior of positrons in solids. Interestingly, it was only in details that the 1956 and 1981 physical pictures differed. In particular, by 1981 a much better understanding of the behavior of positrons in metals when they reached thermal equilibrium and diffused near the sample's surface had been achieved. Under those conditions there is a finite probability that the positrons will be ejected from the sample. This in turn permitted the production of variable-energy, slow positron beams. The development of such high-intensity positron beams by Berko and his colleagues, Karl F. Canter and Allen P. Mills (1974), led to new applications of slow positron physics to surface studies, and to the possibility of forming positronium in vacuum and to novel experimental studies of the fine structure of the 1S, 2S, and 2P states of positronium. Both of these investigations were undertaken at Brandeis University.

The following overview sketches the motivation for, and the results of, Berko's experimental investigations in positron physics. It draws heavily on Berko's 1981 Varenna lectures and from his joint paper with Hugh Pendleton on positronium (1980).

In a typical experiment, positrons from a long-lived radioactive e+ source, such as 22Na, 58Co, or 64Cu, are injected into a gas, liquid, or solid, the substance to be studied. These positrons initially have the usual energy distribution of a ß+ spectrum. In a crystalline solid they lose their energy rapidly (within 10-12 to 10-11 sec depending on the composition of the sample) by ionization, electron-hole pair creation and at low energies by positron-phonon scattering, and attain thermal equilibrium with the lattice. In a metal positron interacts strongly with the conduction electrons, the latter forming a screening cloud around the positron. In their lowest energy states, as first shown by Berko and Plaskett, the positrons' wave functions are periodic, delocalized Bloch waves, with minima at the position of the positive ions and maxima at the interstitial sites. Positrons that do not form Ps or some other bound molecular compound annihilate with conduction electrons with a lifetime of a few tenth of a nonosecond. The annihilation products are governed by quantum electrodynamic selection rules: for spin-singlet e^+-e^- states annihilation proceeds via the 2γ channel, whereas the triplet state decays into 3 photons. The energy distribution of a photon from the 3γ annihilation of the spin triplet state exhibits a characteristic three-body decay spectrum ranging from 0 to mc^2, whereas the photons from the spin singlet 2γ decay are nearly mono-energetic. Since the 2γ annihilation cross-section is roughly 10^3 larger than the 3γ cross-section, positrons in metals annihilate mainly via the 2γ channel. The angular correlation of the annihilation radiation (ACAR) and the energy spectrum of the annihilation γs reveal, by energy and momentum conservation, the momentum distribution of the annihilating e+-e- pair. Discontinuities in the angular correlations reflect the size and topology of the Fermi surface of the metal, while lifetime experiments yield information about the local electronic density at the position of the positron. In ferromagnetic materials, the 3γ/2γ yield from spin aligned positrons combined with ACAR measurements can provide information about the spin-aligned electronic bands. Furthermore, since the effect of temperature on the Fermi surface is negligible compared to the effect of temperature on the motion of the positron—the relation between momentum and temperature of the positron is given by $P_+^2/2m=3k_BT/2$—the temperature dependence of the positron-many electron interacting is important and observable.

As demonstrated by Berko in his Varenna lecture, positron annihilation had become by 1980 an important tool in solid-state physics with ACAR and positron lifetime experiments yielding valuable new important structural information. In addition, positron annihilation experiments made it possible for theorists to test the degree to which their models and calculational approximations accurately described such "well-understood samples" as nearly-free-electron metals.

Berko recognized early the usefulness and importance of positron annihilation in condensed matter physics and was one of the principal contributors to the development of the field. With his students and collaborators, Berko made significant contributions to many areas of experimental positron physics, and in particular, to the instrumentation of 2γ angular correlation (ACAR) experiments.

In the Varenna lectures Berko also described the 64 detector 2D ACAR system built at Brandeis. The lectures culminated with a review of ACAR work in metals carried out by him and his students and by experimenters elsewhere.

Rather than presenting further details of Berko's impressive achievements I list below the experimental work identified by L. O. Roellig—one of the most respected scientists in positron physics—in the preface of the proceedings of the symposium celebrating Berko's 60th birthday (Mills et al., 1986):

- The theory of ACAR experiments using spin-polarized positrons. Berko developed the theoretical and experimental foundation for the use of spin-polarized positrons as a probe of the electronic structure of ferromagnetic materials (1967).

- The test of many-body theory by high-precision, accurate measurements of positron annihilation rates in alkali metals (1967).
- One of the first papers on positron trapping in disloca tions in metals (1967).
- The first mention of delocalized positronium states (1970).
- Several papers on positron annihilation in disordered alloys (1974).
- The first paper to show that positronium can be produced by a beam of low-energy positrons (1974).
- The first high-precision two-dimensional ACAR studies (1975, 1976, 1977).
- The development of techniques for three-dimensional reconstruction from two-dimensional ACAR in order to study Fermi surfaces (1979, 1982).
- The application of the two-dimensional ACAR technique to the study of the electronic structure at point defects in metals (1982).
- From 1982 to 1989 Berko worked with the positron group at the Brookhaven National laboratory to study the inter action of slow positrons with solid surfaces using 2D ACAR methods. One of the notable papers that ensued from that collaboration dealt with ACAR measurement of positrons on the surface of a metal (1985). The data obtained in these measurements indicated that the usual model of a positron bound in a surface state by its "image-correlation potential" or a positronium atom weakly bound to the surface was not valid.

After 1989 Berko became involved in the study of high temperature superconductors, the characterization of polymers, and momentum density measurements in semiconductors.

POSITRONIUM

During the 1970s several laboratories developed slow positron beams with controllable energy and of sufficient intensity to serve as a source for further experiments. This important advance was based on the discovery that when fast positrons from e^+ sources are moderated in solids a fraction of them are ejected from the surface. By 1972 Canter, Mills, and Berko were able to achieve an efficiency (number of slow positrons ejected per second divided by the total number of positrons ejected by the source per second) of 3×10^{-5} and an energy width of approximately 2 eV. The first Brandeis experiment with the positron beam was designed to study the interaction of slow positrons with surfaces. It yielded the unexpected finding that when positrons between 20 and 30 eV were directed at the surface, more than half of them would be reemitted as Ps from the surface into the vacuum. The discovery that Ps could be efficiently produced in vacuum far removed from the background radiation of the radioactive source—not only in its ground state but also in excited states—resulted in outstanding experimental researches at Brandeis on the spectrum of Ps.

Karl Canter, Allen Mills, and Berko (1974) were able to observe directly the Lyman-α photons. Thus ended the search begun 20 years earlier when Kendall and Deutsch unsuccessfully attempted to observe this radiation by optically pumping Ps in the n=1 state with an arc lamp to the n=2 state and detecting the subsequent decay.

Martin Deutsch, who was the first to produce positronium in low density gases in 1949, together with his students devised most of the methods for the detection of Ps. He measured the triplet and singlet lifetimes of the Ps ground state. Deutsch and his students also determined the fine structure interval by considering the Zeeman mixing of the n=1 Ps levels in the presence of a magnetic field.

In 1954 Kendall and Deutsch unsuccessfully attempted to form Ps in the n=2 excited states in a gas by optically pumping the n=1 states with an arc lamp and thereafter detecting the Lyman-α radiation when the Ps made a transition from the n=2 to the n=1 level.

High-precision studies of positronium are important, for it is a leptonic atom for which the electroweak Hamiltonian is believed known. e^+ and e^- being antiparticles of one another, there is a new set of Feynman diagrams that enter in the calculation of their interactions that are not present in the electron-proton interaction. These diagrams arise because an electron and a positron can come together, annihilate into a virtual photon, and then reemerge as an electron and positron.

The papers by Berko, Canter, and Mills on the Lyman-α line and the Lamb shift in Ps were cited by the American Physical Society as among the most important physics papers published in 1975 and acclaimed as an outstanding experimental feat.

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