Britain, it was very much Todd's creation, in terms of both modern equipment and of structure. A small wing was first built and then tested (almost to destruction) by his staff, with lessons learned then passed on to the architects. Refurbishment was not needed until the mid-1990s.

Todd was becoming increasingly involved in academic politics and foreign travel, his first visit to Southeast Asia being in 1958. In the late 1950s he attended meetings at the home of Winston Churchill about the foundation of a new college where science and technology were respected. This became Churchill College, with Todd as a trustee. From 1955 he served on the council of the International Union of Pure and Applied Chemistry, and from 1963 to 1965 was its president. By now he was a close friend of the American chemist Robert Burns Woodward, and together they would often attend conferences overseas. He was frequently invited abroad to receive honorary degrees. India, the United States, and (especially) Australia were among his favorite destinations.

In 1962 he was awarded a life peerage, with the title of Baron Todd of Trumpington, and took his seat on the cross-benches of the House of Lords. The next year he was appointed master of Christ's College, Cambridge. In 1965 he became the first chancellor of the University of Strathclyde and also chairman of the Royal Commission on Medical Education. Further demanding trips abroad, and extensive cigarette smoking, were beginning to take their toll, and in 1970 Todd suffered a massive heart attack. During his convalescence he attempted to teach himself Chinese. Taking warning from the episode, he resigned his chair the next year. He managed, however, to preside at the British Association in September 1970.

Other tasks however followed. Todd became chairman of the syndics of Cambridge University Press, then in the doldrums and in need of fresh ideas. These he supplied, and saw the press begin its rise to prosperity and success. He was also prevailed upon to become chairman of the managing trustees of the Nuffield Foundation in 1973. Then, in 1975, came an honor that he seems to have appreciated most: he became president of the Royal Society in 1942. His aims were to increase the influence of the society on government, to support research by funding further research posts, to relate more closely to technology, and to strengthen the society's international relations. In setting future trends in all these areas, he seems to have had considerable success during his five-year tenure. He received the Order of Merit in 1977. A few other appointments followed, but gradually he let go of committee work while maintaining former friendships and an interest in the progress of science in Britain. In 1987 his wife died; he survived for another ten years, in the care of his former secretary, Barbara Mann. His own death came on 10 January 1997 at a nursing home near Cambridge, from heart disease and pneumonia. He died a millionaire.

Alexander Todd was of striking appearance, over six feet six inches tall, with a strong Glaswegian accent. Even in the laboratory he dressed as a patrician, immaculate in a pin-striped suit, reflecting an awareness of how far he had traveled from his working-class origins. He did not like party politics, especially of the left, a tendency inherited from his father. Conservative by nature, he objected to student protests, and reacted strongly against the proposals of the Robbins Report of 1963 for extensive expansion of the universities. He believed this would lead to a diminution of standards and that the small number of very talented students would suffer. This was elitism, but in an academic rather than a social sense. Deemed arrogant by many, he possessed insatiable ambition and great tenacity. He had a fine sense of humor, which frequently surfaces in his well-written autobiography. He has been said to have had a "huge presence" in Cambridge, and his massive contribution to science policy, coupled with his immense achievements in organic chemistry and in biochemistry, make him one of the great men of twentieth-century science.

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Colin Russell

TOUSCHEK, BRUNO (*b.* Vienna, Austria, 3 February 1921; *d.* Innsbruck, Austria, 25 May 1978), *theoretical particle physics, statistical mechanics, particle accelerators.*

Touschek

Touschek is considered a pioneer in the field of matter–antimatter colliders. Both a theoretical physicist of elementary particles and an expert in accelerator problems, he also provided contributions to the fields of statistical mechanics, discrete symmetries, neutrino problems, and quantum electrodynamics.

Early Days and War Experience. Touschek was born in Vienna in 1921; he was the son of Franz Xaver Touschek, a staff officer in the Austrian Army who participated in World War I on the Italian front, and Camilla Weltmann. The epidemic Spanish flu in 1918 had left his mother in poor health, and Bruno only saw her in bed until her death in 1931.

In July 1934, after the assassination of the Christian-Socialist Engelbert Dollfuss by the National Socialists inspired by Adolf Hitler, the Nazis renewed Austria's latent anti-Semitism. Because Bruno's mother had been Jewish, he was banned from attending the Gymnasium in 1937, one year before the final state examination (the *Abitur*). He applied to take this *Abitur* as an external student at a different school, and passed the exam.

He then went to Rome for the school holiday and attended the first engineering university courses. But in the summer of 1938 he returned to Vienna. When, in September 1939, World War II began, Bruno's father refused to reenter active service; Bruno was very proud of this.

He decided to study physics and mathematics at the University in Vienna. He tried not to attract attention, but soon he was clearly the best student in the courses so that his origin was identified and in June 1940 he was expelled. Many outstanding professors helped him, among them Paul Urban and Edmund Hlawka, then Arnold Sommerfeld in Munich and Paul Harteck in Hamburg. Touschek moved to Hamburg and worked for a firm, Opta, originally Jewish property. In Hamburg, he studied betatrons and met Norwegian physicist Rolf Wideröe.

Unfortunately, the Gestapo noticed him and he was arrested at the beginning of 1945 because of his Jewish mother. Wideröe visited him frequently and bought him books, food, and cigarettes. He was taken with a group of prisoners from the Hamburg prison at the beginning of March 1945 and routed to a camp near Kiel; he had a high fever and collapsed in the ditch near the road. An SS officer shot at his head but only wounded him. During the rest of his life, Bruno told several slightly varied accounts of the events that immediately followed. To his Italian colleague Carlo Bernardini he recounted that some civilians realized he was not dead and brought him to a hospital. There he was treated but betrayed to the police. He then was transferred to the prison of Altona.

Post-War Positions. Freed by the English in June 1945, Touschek refused to accompany the troops as an interpreter. At the beginning of 1946, he reached Göttingen where he found physicists Ludwig Prandtl and Werner Heisenberg, among others. Touschek worked on the theory of the betatron, a machine that used magnetic induction to accelerate electrons in order to generate both high energy electrons and x-ray beams. This constituted his thesis work, and Touschek received the title of "Diplomphysiker" under the guidance of Richard Becker and Hans Kopfermann. He then began working with Heisenberg, writing a paper on double beta decay and a second one on the mathematics of the Schrödinger equation. Meanwhile, he was appointed as research worker at the Max Planck Institute in Göttingen. In February 1947, he moved to Glasgow where he started collaborating with Philip Dee and then with John Currie Gunn, who had formed a theoretical group there in 1949. In Glasgow, Touschek worked on nuclear physics with Ian Sneddon and on electron collisions, proton collisions, and meson production with Gunn and Edwin Power. He also published some work in field theory concerning bound states and divergences.

When Walter Thirring from Vienna reached Glasgow in 1950, Touschek immediately worked with him on "Bloch-Nordsieck method," a calculational technique in quantum electrodynamics (QED), which had been developed in 1937 to deal with the infrared divergence of the radiation spectrum: this problem was henceforth a leitmotif in Touschek's ideas. QED was the quantized theory of matter and energy which had replaced James Clerk Maxwell's classical theory of radiating electric charges.

Eventually, Touschek was drawn to Rome by the presence of his mother's sister Ada, who had married an Italian gentleman before World War II. His grandmother Josepha had also lived in Rome with her daughter Ada until the beginning of the war, at which time she returned to Vienna. She had been arrested by the Nazis in 1941, sent to the Theresienstadt concentration camp, and killed there. In Rome, Touschek was in contact with Bruno Ferretti, who, in 1948, had replaced Gian Carlo Wick at the University of Rome. In September 1952, Touschek was offered the possibility of remaining in Rome through a position at Italy's INFN (National Institute of Nuclear Physics), which he accepted. Touschek went back to Glasgow only to marry Elspeth Yonge, the daughter of a well-known zoologist in Edinburgh: they soon came to Rome where their sons Francis and Stefan were born (in 1958 and 1961).

Projects and Teaching. In a couple of years, before Ferretti's transfer to Bologna, Touschek illustrated his ideas to many young people: he was fascinated by neutrino physics and in some way speculated on the unification of weak and electromagnetic forces, anticipating some concepts of the later electroweak theory of S. Weinberg and A. Salam.

In 1950 and then again in 1952, the strong-focusing principle had been proposed for synchrotron-type particle accelerators—first by Nicholas Christophilos in an unpublished work and then independently by Ernest Courant, M. Stanley Livingston, and Hartland Snyder in a *Physical Review* article. In 1953 Touschek, along with Matthew Sands from Pasadena (California Institute of Technology) worked on practical stability problems. At almost the same time, he was collaborating with others on projects such as the decay of the so-called tau meson and a model for photoproduction of mesons. Following that work, Touschek collaborated in a large variety of fields: field theory and perturbative methods (particularly the Tamm-Dancoff method); discrete symmetries and time reversal; and conservation of leptonic number and γ_5 invariance. Touschek was very generous and stimulated continuous discussions in many different fields. Many of his ideas actually can be found in the papers of his pupils and colleagues.

Touschek was a very brilliant teacher: from 1953 to 1963 he gave advanced courses for postgraduates in the Physics Institute of the University of Rome, then he interrupted this activity to dedicate more time to his work at the Frascati Laboratories, 30 kilometers from Rome. He contributed many lectures both to the Scuola Normale Superiore in Pisa and to the Scuola Internazionale di Fisica in Varenna (where he directed some of the summer schools). He had many excellent pupils, among them Nicola Cabibbo, Francesco Calogero, Giovanni Gallavotti, and Paolo Di Vecchia. He also maintained close contacts with outstanding physicists like Wolfgang Pauli and Eduardo Caianiello, in addition to the Austrian colleagues he had met just after the end of the war. His university career in Italy was not easy because of the laws preventing foreigners from taking permanent positions: he refused to become an Italian citizen, and this caused some problems. He was nevertheless accepted as a member in the famous Italian Accademia dei Lincei. Meanwhile, he had many contacts with the Austrian goverment who wanted to restore Austrian research with the help of distinguished citizens working in other countries: Bruno Touschek and Victor Weisskopf among them. This project never went to a conclusion; still Touschek often dreamt about it.

Particle/Antiparticle Collisions. The turning point in Touschek's life came with a seminar he gave on 7 March 1960 at Frascati. He had already had a "strong feeling" about the physical importance of charged particle–antiparticle collisions in a single magnetic ring. The feeling, as Cabibbo remembered, had originated during a seminar in Rome given by Stanford University physicist Wolfgang Panofsky. In that seminar, Panofsky was illustrating the tangent, double rings under construction by a Princeton-Stanford collaboration to explore electron-electron scattering at very high center-of-mass energies. Touschek already knew of the technical possibility of center-of-mass collisions in beam-beam configurations through his friend Wideröe. Wideröe had patented the idea in 1943 with an enlarged scope after Touschek expressed his disdain for the original patent application because—he often said later to his colleagues—one cannot patent trivial ideas. According to both Cabibbo and colleague Raul Gatto, Touschek made the comment at Panofsky's seminar that electron-positron physics might be much more interesting than electron-electron, because (in his picturesque language) this would "excite the vacuum" in a much cleaner initial state.

In the electron-electron scattering process, the two colliding electrons survive, possibly accompanied by photons. In electron-positron collisions, the initial particles can actually annihilate one another. They disappear in to pure electromagnetic energy, all of which is subsequently reconverted into new particles.

The Princeton-Stanford group did not immediately pursue the suggestion: nobody had seen a positron beam up to that time. Moreover, because of the extraordinary successes of Stanford physicist Robert Hofstadter on form factors, particularly the proton and neutron form factors, the Princeton-Stanford collaboration were interested in checking the reliability of Quantum Electrodynamics (QED), hoping to discover any possible structure possessed by what QED assumed to be "point" electrons; their machine was the appropriate instrument for this.

Therefore, Touschek decided to bring his idea to Frascati, where an excellent 1,100 MeV (megaelectron volt) electron synchrotron was just starting operations. Meanwhile, he alerted Frascati-ROME physicists Cabibbo and Gatto in order to get a panoramical view on the important processes to be studied by electron-positron annihilation. Cabibbo and Gatto quickly prepared a comprehensive paper on all possible outcomes of electron-positron annihilation; this paper was immediately called "the bible." In Touschek's seminar on 7 March 1960, he tried to convince the director of Frascati, Giorgio Salvini, to convert the synchrotron into a "collider," and, after Salvini's strong refusal, agreed try with a small prototype, AdA (from Anello di Accumulazione, Italian for "storage ring"—but also a nod to his beloved aunt Ada for those in the know). The prototype would study collisions of electrons and positrons of 250 MeV per beam.

In laboratories dedicated to high energy physics, two kind of specialists were cohabiting, experimental physicists and accelerator designers. Designers were planning quite sophisticated accelerator components and were mostly willing to build prototypes to test the adequateness of these components toward such goals as injection rate, stability of orbits and focusing, circulating currents, and so on. Physicists were afraid to waste time in realizing such sophisticated opportunities. The peculiarity of AdA was its conceptual simplicity, focusing on the main goal which was the experimental demonstration of the "luminosity formula," that is, of the actual complete overlap of the two opposite beams in the collision zone. The design did not attempt any of the sophisticated possibilities that "machine people" were suggesting at the time. Instead, at Frascati, the choice was made to plan two different rings, AdA as a simple demonstration device and a second, larger machine, Adone, as a "professional" machine. (Again, note the double entendre of the moniker: *Adone* in Italian means "large Ada" but it is also the Italian name for the Greeks' mythological Adonis.) Adone was approved in a rapid decision by the directors and presidents of the institutions involved (mainly the INFN, the CNEN [National Nuclear Energy Committee], and the LNF [Frascati National Laboratories]). Touschek also contributed to the design of Adone as a strong-focusing, separated-function (with bending, magnetic dipole sections plus separate, focusing, quadrupole magnets), single ring capable of storing 1.5 GeV (gigaelectron volt) beam of electrons and positrons (2×1.5 GeV following the present notation).

The design of AdA was quickly completed by the Frascati staff (including, besides Touschek, Carlo Bernardini, Gianfranco Corazza, and Giorgio Ghigo), the magnet was ordered, together with the radiofrequency cavity and the vacuum chamber—complete with ion pumps. The Frascati Labs were extremely cooperative so that by 27 February 1961, injection trials with AdA were already being attempted. Touschek was extremely excited, notwithstanding some difficulties in the injection procedure.

A linear accelerator was considered as an injector of both (1) electrons and (2) positrons produced at an efficient converter. The gamma ray beam of the main synchrotron at Frascati was too weak to meet the internal conversion performances needed for a reasonable positron or electron injection rate in AdA. Hence, the main improvement after the February 1961 trials was to accept the offer of the Orsay Labaratory in France to use their linear accelerator. Because the cleaning of the chamber had taken several months to reach the low presure of 10^{-9} torr, the ring, complete with the vacuum system still in operation, was transported across the Alps. Once it reached Paris the virtues of the Orsay Linac were appreciated immediately. A novel injection procedure was adopted, including a modulation of the radiofrequency amplitude during the now very short Linac pulse, and the injection rate increased by no less than two orders of magnitude. Pierre Marin and François Lacoste from Orsay joined the Italian group which meanwhile had included Giuseppe Di Giugno and Ruggero Querzoli; then, Lacoste left and was replaced by Jacques Haïssinski. All together, the AdA staff was reasonably sized and Touschek, who abhorred large groups, was happy and satisfied.

At the beginning of 1963, the injection worked well, lifetimes of the beams were in the 10-hour range and a luminosity trial was in preparation. However, during a run at 195 MeV with a single beam injected, a saturation effect of the injection rate manifested itself. Interpolating the data, it was realized that the lifetime of a beam contained an unexpected correction term proportional to the particle number in that beam. Touschek found the mechanism of the phenomenon by spending some hours that same night working on it: he understood that there was a large momentum transfer from the radial to the longitudinal motion in a particle bunch due to the scattering of these particles within the same bunch. Since, the longitudinal motion had a much narrower stability region than the radial "betatron oscillations," many particles were lost when the density in the beam had reached a relevant value. Touschek had rapidly calculated the energy dependence, showing that it was luckily decreasing as $E^{-9/2}$. Because this effect could have been devastating for the operation of the larger machine, Adone, it was very reassuring to see that it would decrease so rapidly with energy. AdA was cured a few days later by inflating the beam with a rotated quadrupole magnet inserted ad hoc in a straight section of the machine, transferring momentum from the radial to the vertical betatron mode, which decreased the transverse beam density.

The discovered phenomenon was named the "Touschek effect." Though it meant that any particle-antiparticle annihilations in Ada would take place at a rate too low to record directly, a disappointment to be sure, it eventually helped in measuring luminosity by using a particular result, the beam-beam bremsstrahlung radiation, as a monitor reaction. The AdA exploitation ended in the autumn 1963; the magnet was brought back to Frascati and some time later was installed under a transparent protection in the grass, as in an open air museum. Touschek was extremely satisfied with this achievement: the feasibility of single ring electron-positron beams had been demonstrated, the luminosity formula checked, and some machine effects discovered.

Meanwhile, the ACO ring (2×550 MeV) had been constructed at Orsay, the VEPP II ring (2×700 MeV) at Novosibirsk, U.S.S.R., was nearly complete, the CEA electron-syncrotron at Harvard would be changed to a 2x2.5 GeV ring, the Stanford Linear Accelerator Center had begun to design a ring which would use its 20 GeV

Touschek

linear accelerator as an injector, and Adone had been approved and construction begun at Frascati under the direction of Fernando Amman. In any case, even with a minuscule luminosiy of $10^{24}/cm^2\ s^1$. AdA was the first machine of the collider series to have registered actual collisions; the Princeton-Stanford's figure-eight configuration and VEPP 1 at Novosibirsk both electron-electron machines initiated a few years before AdA, went into operation some years later.

Touschek was very proud of the short time the staff had employed to complete the work. Moreover, everybody in high energy experimental physics was now convinced that future research activities in the field would require matter-antimatter colliders.

Final Years. In the years from 1964 (the end of the work with AdA) to 1978 (his death), Touschek worked and taught both in Italy and at CERN. He was highly celebrated and traveled around the world to talk about colliders. At the same time he collaborated, often with young students, on some very exotic theoretical possibilities: two-neutrino photon theory, relativistic reformulation of statistical mechanics, speculations on the possible "milestones" in high-energy physics, and reexamination of the classical Thirring effect on rotating frames in general relativity. Additional, very important work on radiative corrections for colliding beams experiments with Giulia Pancheri and E. Etim has since been known as the "discovery of the Bond factor" because of a numerical exponent B evaluated to be 0.07.

When the student "revolution" came, after 1968, Touschek no longer wanted to spend his hours at the university: a group of ignorant young protesters once called him "Nazi" and he did not want to reply, because he after all respected youth. Therefore, he retired to his home where he spent some time considering possible thresholds of high-energy physics: he sent a paper to *Physics Letters B* indicating his address as "Garvens, Roma, Piazza Indipendenza," the firm he had inherited from his beloved aunt Ada.

In those years, a scandal had developed in Italy: the "Ippolito case," following the "Mattei affaire." Felice Ippolito was the head of the Italian organization for nuclear energy; he was accused of having profited from his position for private interests. Edoardo Amaldi, the dean of Italian physicists, defended Ippolito against the politicians accusing him, discovering that an oil lobby was behind the attacks. The meetings of the group of scientists supporting Amaldi were held in Touschek's house. Touschek was quite upset by the situation, particularly when Ippolito was unjustly condemned for a ridiculous crime, "international embezzlement" (which did not exist in jurisprudence). Touschek decided to dedicate some time to education in the schools and collaborated with the Accademia dei Lincei to improve scientific communication to the public. He gained many fans among teachers. His message to the teachers consisted in showing the importance of qualitative understanding of scientific problems.

For a time he considered the possibility of moving to CERN in Geneva. While visiting there, he was involved in the stochastic cooling of antiprotons with regards to the new proton-antiproton ring and wrote a Frascati prepent, his last work. His health was very poor: on 25 May 1978, Touschek died in the Medical Ward of the University Hospital, in Innsbruck, after a series of hepatic comas at the age of only 57. He had already suffered from such attacks since February 1977. Apart from his extremely brilliant scientific activity, he left a large number of vivid memories: his drawings (in the style of Egon Schiele), his quotations from the Viennese satirical literature (particularly Karl Kraus), his teaching abilities, his generosity with the young students, and his rigor with colleagues.

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Carlo Bernardini

TOUSEY, RICHARD (*b.* Somerville, Massachusetts, 18 May 1908; *d.* Cheverly, Maryland, 15 April 1997), *vacuum ultraviolet techniques in photometry and spectroscopy, optics, solar physics, space science.*

Tousey, a laboratory spectroscopist and optical specialist who worked most of his career at the U.S. Naval Research Laboratory (NRL), led a team that was the first to successfully design, build, and fly a spectrograph on a captured German V-2 missile that produced a photographic record of the ultraviolet spectrum of the Sun, never before seen by humans. Tousey remained a central figure active in ultraviolet solar research with rockets, satellites, and human spacecraft throughout his career, and mentored several generations of space scientists.

Born in Somerville, Massachusetts, on 18 May 1908 to Adella Hill Tousey and Coleman Tousey, a dentist, Richard Tousey recalled being especially influenced by his early schooling at what was at first called the Harvard Cooperative Open-Air School and later the Shady Hill School. There he gained a deep fascination and appreciation for nature, which was enhanced by summers at a series of family homes on the Maine shore, where he was encouraged to learn to sail with his brother and sister. His fascination continued through grade schools and was further stimulated by a family friend, John F. Cole, who introduced Tousey to his machine shop and extensive library and took an interest in the astronomical basis for navigation, which he shared with Tousey. Cole helped Tousey build a crystal receiver, learn Morse code, and then learn about vacuum-tube electronics.

Tousey entered Tufts University at age sixteen, the third generation in his family to do so, living at home and supported by his family. His interest in radio steered him into physics courses, but he was not committed to a career at first, ultimately taking a combined physics and mathematics curriculum. Graduating with highest honors in 1928, he entered Harvard University in physics, but still had not acquired any clear goals. He continued to explore options through contact with John Clark Slater and Theodore Lyman, and finally chose experimental physics under Lyman, because Lyman suggested a topic, the reflecting power of metals in the extreme ultraviolet, that encompassed Tousey's interests in solid-state physics gained under Slater.

Tousey was awarded the MA in 1929, taking courses under Friedrich Hund and Frederick A. Saunders, with whom he shared a strong interest in birding (both were members of the Nuthall Ornithological Club). The PhD came in 1933, and by then Tousey very much followed in Lyman's path, exploring a wide array of questions that required expertise in the vacuum ultraviolet. Tousey designed a vacuum spectrograph to study the optical characteristics of fluorite, a crystal that remains transparent deep into the ultraviolet and so can be useful for vacuum ultraviolet instrumentation. Throughout his graduate years, though his family continued to be prosperous, Tousey was largely supported by a series of substantial Harvard physics fellowships: the Whiting (1929–1931), the Tyndall (1931–1932), and the Bayard Cutting, which he won two years in a row, supported by Lyman. His 1936 thesis put him into contact with the machinist David Mann, head of the Physics Department shop, with whom he had a long fruitful collaboration. Tousey became especially adept at making his vacuum systems efficient and reliable, searching for leaks and handling humidity problems, though he recalls a certain amount of impatience working through the elaborate procedures Lyman had developed.

Tousey married Ruth Lowe in 1932. They met as undergraduates at Tufts, and shared interests in classical music, especially chamber ensembles, which they often entertained at their home.

After graduation Tousey stayed on in Lyman's laboratory as a tutor and laboratory researcher/instructor. He further developed his thesis for publication, mainly searching for refinements to methods in photographic