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Fritz Rohrlich and His Work—On the Occasion of His Retirement

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Fritz Rohrlich was born in Vienna, Austria, on May 12, 1921, as the only child of the lawyer Egon Rohrlich and his wife Illy, née Schwarz. His seven year older half-brother, George, lived with his father's first wife (Rosa Tenzer), but spent his weekends usually at his father's home. George was to play an important role in the life of Fritz. Both of them attended the same high school, the *Realgymnasium* in Vienna's first district. It must have had good science teachers, for it produced a number of distinguished physicists, among them Victor F. Weisskopf.

Fritz's interest in the physical sciences was stimulated by his teachers as well as—and perhaps even more—by George who used to supply him with books on popular science, as well as on philosophical and ideological issues, such as Häckel's *Die Welträtsel*, Spinoza's *Ethics*, and Pinsker's *Autoemanzipation*. The greatest influence upon Fritz's mind, however, had Hans Reichenbach's *Atom und Kosmos*, for it led him to the decision to study physics and philosophy at the University of Vienna. But political events thwarted the realization of this plan. In March 1938 Hitler marched into Vienna. Fritz had to leave school without obtaining the high school diploma that would have entitled him to study at the University. His application to study at the Hebrew University in Jerusalem was turned down on the ground that the applicant had not completed high school. But having had, fortunately, applied for enrollment also at the Haifa Institute for Technology, he was able to leave for Palestine on a Technion student visa in February 1939. His parents were not allowed to join him because the British Mandatory Government, yielding to Arab pressure, did not permit

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adult immigration at that time. In the spring of 1942 they were deported by the Nazis from Vienna to Poland and murdered in the gas chambers of Sobibor.

When Fritz Rohrlich arrived in Haifa his knowledge of Hebrew, the language of instruction at the Technion, was almost nil. Still, thanks to this excellent high school education, he managed to pass the June 1939 final examinations for the freshman year. Since the Technion at that time did not offer a degree in physics, Fritz graduated in industrial chemistry and electrical engineering, the subjects closest to physics he could choose. At the end of the war he moved to Jerusalem. At night he worked there as a maintenance engineer at a short wave transmitter for the British Army, and by day he attended the physics lectures at the University. The two most influential teachers he had in Palestine were Franz Ollendorf, the dean of the faculty of electrical engineering at the Technion, who taught him to solve mathematical problems in physics and engineering, and Giulio Racah, the head of the department of theoretical physics at Hebrew University, who introduced him to research. Although fully aware of the fact that Rohrlich was only an external student, Racah gave him an assignment in atomic spectroscopy as preparation for a Ph.D. work. It was based on an application of Racah's method of tensor operators for the calculation of the energy matrices of the configurations d^2sp, d^3p, and d^7p occurring in Ti I, Fe I, and their isoelectronic sequences.

The long shifts at the transmitter station gave him an ideal opportunity to study thoroughly the relevant literature, such as Condon and Shortley's *The Theory of Atomic Spectra* and, of course, all of Racah's papers on atomic spectra. Yet, in spite of promising results, Rohrlich did not finish the assignment in Jerusalem for the following reason. His stepbrother George, after having obtained in Vienna two doctorates, one in Law and the other in Political Science, emigrated in 1938 to the United States and worked there for a third doctorate at Harvard University. Due to his efforts, Fritz also was enrolled at Harvard. In fact, he was accepted as a graduate student in physics without ever having had any undergraduate training for a physicist. Informed of his acceptance, Fritz left Jerusalem and embarked in Haifa on a Merchant Marine ship that arrived after a month-long journey via Malta, Marseille, and Casablanca in Baltimore on February 10, 1946. Having no money and anxious to earn an income, Fritz rushed through the Harvard requirements for an M.A. in 1947 and for a Ph.D. in 1948 with Julian Schwinger as his thesis advisor. The subject of this thesis was the application of the phase method and the Born approximation to the calculation of the cross sections of high-energy neutrons scattered by protons and neutrons. The results of this study were recorded in the first of his papers, a Letter to the Editor in

The Physical Review of 1948, written together with Julian Eisenstein, and in a more detailed exposition in the *Physical Review* of 1949. At the same time Rohrlich, now under the sponsorship of John Hasbrouck Van Vleck, completed the assignment given to him by Racah. The results of these calculations were reported in two papers published in Vol. 74 of *The Physical Review*.

Rohrlich's official position at Harvard was now that of a teaching assistant to Norman Foster Ramsey. When in the course of the semester Ramsey fell sick with chicken pox, Rohrlich substituted for him. This was Rohrlich's first teaching experience. In 1948 he left Harvard for Princeton where Robert Oppenheimer, the director of the Institute for Advanced Study, had offered him a membership at the Institute. For Rohrlich this was one of the highlights of his life: he met Einstein, Pais, Placzek, Uhlenbeck, Dyson, and the mathematicians Gödel, von Neumann, and Weyl; he was present when von Laue and Yukawa visited the Institute. What fascinated him most were the seminars conducted by Oppenheimer whom he admired for always being two steps ahead of the speaker.

In 1949 Rohrlich became Research Associate to Hans Bethe at Cornell University where he fell under the spell of Richard Feynman and Philip Morrison. It was at Cornell where he began his research in classical and quantum electrodynamics and the intertheoretic relations between them, a subject in which he was to become a leading authority. The first problem that attracted his attention was the divergence of the electron's self-stress, which, like that of the electronic self-energy, had already troubled the Lorentz–Abraham–Poincaré classical theory of the electron. To be sure, the Pauli and Villars cutoff procedure of introducing Lorentz and gauge-invariant auxiliary fields or "regulators" removed the divergences of the self-energy from the *S*-matrix to all orders in the expansion in the coupling constant, but it proved unsuitable to tackle the self-stress problem. By carrying out the integrations with the Feynman method, Rohrlich showed that the introduction of the regulators right at the beginning of the theory, that is, in the Lagrangian density, leads to a vanishing value for the self-stress and proved the consistency of the relativistic formalism (*Phys. Rev.* 77).

At Cornell, Rohrlich discovered that the spin-zero quantum electrodynamics cannot be normalized without the introduction of a contact interaction, an issue on which he had an interesting exchange of letters with Wolfgang Pauli. Rohrlich also showed at that time (1950) that the Feynman and Schwinger–Tomonaga formulations of quantum electrodynamics are equivalent, i.e., lead to identical scattering matrices, not only, as Dyson had demonstrated, for the interaction of electrons with the electromagnetic field, but also for spinless charged particles (*Phys. Rev.* **80**).

The work of Dyson and of Rohrlich contributed decisively to the rapid increase in the popularity of the Feynman method since it proved to be the simpler and easier alternative, as shown also by Rohrlich's calculations (with W. A. Newcomb) of the Lamb shift for spinless electrons (*Phys. Rev.* **81**).

That there are, nevertheless, certain circumstances in which the Feynman procedure may involve more complicated calculations than other methods Rohrlich recognized when investigating, in cooperation with Bethe and R. L. Gluckstern, the so-called Delbrück scattering. As will be recalled, in the early Thirties Lise Meitner, experimenting at her Berlin laboratory, discovered scattered radiation components much too high in frequency to be interpreted as coherent scattering due to the bound inner-shell electrons (Compton scattering). Max Delbrück, who at that time had still been working with her before he laid the foundations of modern molecular biology, proposed, without any calculations, that this scattering could be explained by pair production in the Coulomb field of the nucleus in accordance with Dirac's relativistic theory. Rohrlich, in collaboration with Bethe and Gluckstern, now studied this phenomenon within the framework of modern quantum electrodynamics. Applying the method of analytical continuation, as first suggested by Jost, Rohrlich calculated the differential cross section for the case of forward scattering of the photon, where its momentum is practically constant (*Phys. Rev.* **86**). Persuaded by Rohrlich to work on this problem, Cornell's experimentalist Robert R. Wilson did in fact succeed in distinguishing the Delbrück scattering from the Compton scattering by the use of extremely good energy resolution detectors (*Phys. Rev.* **90**).

In 1951 Rohrlich returned to Princeton to lecture on quantum electrodynamics which at that time was still a novel and somewhat controversial subject. Eugene Wigner, for example, was still skeptical about it because of its notorious infinities. Nevertheless, he arranged for the lecture notes of Rohrlich's course on quantum electrodynamics to be mimeographed, for they were eagerly sought after not only by Rohrlich's students. During the two years in Princeton, Rohrlich concentrated his activities on teaching much more than on research. But it was not labor in vain. For in 1953 Josef Maria Jauch, who seven years earlier had left Princeton for the State University of Iowa, invited Rohrlich to join him in writing a book on quantum electrodynamics, designed to fulfill the urgent need for a comprehensive treatise that would cover the post-war developments in this field. Their co-authored *Theory of Photons and Electrons*, published in 1956, became—partially at least due to Rohrlich's teaching experience in this subject—a standard text. The first chapters, presenting the general covariant formalism of localizable fields, based on Schwinger's action principle and applied to free photon and electron fields, followed by a discussion on the coupled electron–photon field and its invariance properties, were written mostly by Jauch; the later chapters on the *S* operator, the Feynman Dyson rules and diagrams for evaluating the matrix elements in series forms, and renormalization procedures and applications of these techniques were for the most part Rohrlich's contributions. The book was well received and favorably reviewed. But what Rohrlich appreciated more than any encomium was Pauli's remark: "The more I read in it the more I like it." Twenty years later, that is, two years after Jauch's death, Rohrlich published an updated second edition of the book which serves still today as an indispensable text for all those who study, or work in, quantum electrodynamics.

During his ten years at Iowa State University Rohrlich worked on a wide range of problems in quantum electrodynamics and published more than 30 papers, among them also papers on atomic spectroscopy, general relativity, and from the early Sixties on, on the self-energy, stability, and equations of motion of the classical electron. His interest in classical particle theory dates from a sabbatical which he spent at Johns Hopkins University. There he realized that the classical theory of charged particles, although widely applied in various fields such as electron optics and particle accelerators, has been largely ignored and neglected since the advent of quantum mechanics, and he felt that the time had come to complete the work which Lorentz, Abraham, and Poincaré had initiated many years ago. "To show that this is indeed possible and that the resultant structure is consistent and beautiful and lives up to the expectations of its founders" became an aspiration to which he devoted himself when accepting, in 1963, the professorship at Syracuse University. The fruit of this work is a unique masterpiece, his treatise on *Classical Charged Particles*, published in 1965 and in an enlarged edition in 1990. With the hindsight acquired in his work on quantum electrodynamics, he succeeded in constructing a self-consistent theory of classical charged particles. It settled the problem of the symmetric and asymmetric energy tensor, accounted for the radiation of a uniformly accelerated charge, and resolved the notorious 4/3 conundrum and the issues related to radiative reaction. As David Park in a review rightly remarked: "We and our students ought to know these results, and to be most grateful to a writer who presents them with such style, insight, and balanced judgment."

Simultaneously with his work on classical and quantum electrodynamics Rohrlich studied certain problems related to general relativity. In a series of papers he presented, in cooperation with T. Fulton and L. Witten, a comprehensive study of conformal invariance with special attention to the transformability of rest mass and its physical interpretation

(*Rev. Mod. Phys.* **34**; *Nuovo Cimento* **24**). What led him from his work on the classical electron to general relativity was the simple problem of whether a freely falling charged particle radiates and, if it does so, whether this radiation contradicts the principle of equivalence. He clarified these issues in a detailed study of electromagnetic phenomena in static homogeneous gravitational fields (*Ann. Phys.* **22**). In the following years Rohrlich showed an unusual versatility of moving repeatedly from one field of research to another: from spectroscopy to nuclear physics, from classical charged particle dynamics to quantum electrodynamics and quantum field theory, and from relativistic point dynamics to string theory, proving himself an expert in each of them in defiance of the traditional rule: *non multa sed multum.* In the Eighties he turned his attention to the difficulties faced in direct-interaction dynamics, the theory that accounts for the interaction of particles without recourse to mediating fields. As presented in his 1981 Barcelona lecture and in a series of papers, many of which were written in collaboration with L. P. Horwitz (*Phys. Rev. D* **23–26**, **31**), Rohrlich's method of solving, within the framework of the constraint Hamilton formalism, the problem of relativistic interacting N-particle systems, both in the classical and the quantum formulation, and of establishing a relativistic scattering theory for covariant constraint dynamics, furthered significantly the development of the theory of direct interparticle interactions.

In the last decade before his retirement in 1991, Rohrlich also became actively involved in the philosophy of physics. As a matter of fact, he had been interested in this subject ever since he read Reichenbach's writings in Vienna. But his preoccupation with purely physical problems has always prevented him from doing any work on the concomitant philosophical issues. Now, in the Eighties, certain more or less accidental events occurred that induced him to work seriously in the philosophy of science. At the 1983 Meeting of the American Physical Society in Washington, D.C., Rohrlich met with his former compatriot Viki Weisskopf, who bemoaned the low standard of the popular literature on modern physics and suggested to Rohrlich to write a nontechnical exposition of the epistemological problems of contemporary physics—without references to Eastern mysticism and the like. At about the same time Rohrlich was also asked to teach at Syracuse University a course on "Concepts in Contemporary Physics" for nonscientists. Influenced by these events, Rohrlich wrote his book *From Paradox to Reality*, which Cambridge University Press published in 1987.

Actually, Rohrlich's involvement in the philosophy of physics has much more deeper roots. He has been, and continues to be, regarded as the highest authority and ultimate arbitrator on certain physical problems of far-reaching philosophical implications. A paradigm case is the debate, fought out in the later Seventies, in the *Journal of Philosophy* (Vols. 73, 74) and *Philosophy of Science* (Vol. 46), between the philosophers John Earman and Charles Nissim-Sabat versus Adolf Grünbaum and Allan Janis, on whether an effect can precede its cause and whether retrocausation is a physical possibility. Obviously, the instantiation of the Newtonian law of motion by the laws of electrodynamics, the Abraham–Lorentz and Lorentz–Dirac equations of motion with their "pre-acceleration" effects, played a prominent role in the discussion. Rohrlich's writings were referred to and quoted almost exclusively by all participants of this debate for the purpose of defending their respective positions. According to Rohrlich, those second-order integrodifferential equations "are causal in the sense of predictability as well as restriction of signal velocity to $\leqslant c$. Causal violations in the sense of preacceleration are in principle implied but are, even in the most favorable cases, outside the domain of classical systems and classical measurements; and there is considerable doubt that effects of this size could be observable in principle even in quantum mechanics." [*Classical Charged Particles* (1965), p. 152.]

Considerations of the validity limits of physical theories and, more generally, considerations of intertheoretic relations in physics played an important role in Rohrlich's work long before they were studied by him from the vantange point of a philosopher of science. The most explicit formulation of his view on these issues can be found in his essay "Established Theories," published 1983 with L. Hardin in *Philosophy of Science* (Vol. 50). In it he proposed criteria to distinguish "mature theories" from "developing theories," defining a theory as "established" if it is a mature and its validity limits are known. Newtonian mechanics and the Newtonian theory of gravitation are "established theories," because their validity limits are set by their respective superseding theories, namely relativistic mechanics and general relativity. Gauging the approximate truth of a theory by its approximation to the next higher superseding theory, Rohrlich came to a conclusion that affirms the cumulativity of knowledge, in opposition to certain well-known trends in the current philosophy of science.

The problem of whether quantum mechanics can be realistically interpreted has been discussed by him in a talk on "Schrödinger's criticism of quantum mechanics" at the 1985 Joensuu Symposium in Finland and in his address on "Reality and quantum mechanics" at the 1986 New York Academy of Sciences Conference. Rohrlich's "quantum realism," briefly stated, rejects the contention, which he regards as questionable even in classical physics, namely that a physical object is real only if every "blurred" value of an observable measured on it *can* in principle be made arbitrarily "sharp"; instead, the "blurring" (i.e., Heisenberg's indeterminacy) is accepted as an ontic characteristic of a quantum object. "Quantum realism" also conceives the nonseparability in the case of entanglements, like that in the "Einstein–Podolsky–Rosen paradox," as a nonclassical ontic property of spatially spread-out quantum systems. On the basis of such an extended ontology, "quantum realism" contends to avoid the difficulties faced by the classical realism of hidden variable theories or by the empiricist-instrumentalist version of the Copenhagen interpretation, while it claims to offer an interpretation which is compatible with empirical evidence as well as with the mathematical formalism of the theory.

The preceding account of Rohrlich's scientific work which hopefully will still increase after his recent retirement is admittedly far from exhaustive. For only few of his numerous papers could be reviewed. To do justice to him one would have to review in addition also his contributions to books, like the well-known series of *Lectures in Theoretical Physics*, edited by W. E. Brittin, or *Perspectives in Geometry and Relativity*, edited by B. Hoffmann, his critical book reviews, as well as his invited lectures delivered at research centers in Austria, Bulgaria, India, Israel, Italy, Poland, Spain, and, of course, the U.S.A. His prolific work is the outcome of a combination of persistent diligence, clever ingenuity, and, above all, an insatiable longing for knowledge. His mind is one of those of which an ancient author once said: "Natura inest in mentibus nostris insatiabilis quaedam cupiditas veri videndi."