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Mozart and Quantum Mechanics: An Appreciation of Victor Weisskopf

Weisskopf had a rare and harmonious blend of sentiment and intellectual rigor. He liked to say that his favorite occupations were Mozart and quantum mechanics.

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Figure 1: Victor Weisskopf at about age 20 (photo courtesy of Duscha Scott Weisskopf)

Victor Frederick Weisskopf, who died on 21 April 2002, was a leading figure in the second generation of theoretical physicists who expanded the reach of quantum mechanics following its discovery in 1925-26. That discovery proved to be the most profound and swift turning point in the history of physics since the time of Isaac Newton. Born in Vienna on 19 September 1908, Viki, as he was called by all who knew him, was too young to do original research in those first watershed years. But, like other outstanding members of his remarkable cohort, Viki was a fast study. He published his first landmark paper[1] at the age of 22.

Viki was eventually to become a major actor in a wide variety of settings, but all these roles were consequences of his achievements as a creative scientist. Therefore we devote here considerable attention to his contributions to fundamental theoretical physics.

As a teenager, Viki became fascinated with astronomy and proudly listed a paper on the Perseid showers, based on a night's observation when he was not yet 15, as his first publication.[2] The rich artistic and intellectual ambiance of pre-Nazi Vienna was to deeply influence his interests and attitudes throughout his life.[3] Among his passions was music. In his youth, Viki became an accomplished pianist and even considered a career as a professional musician.

The excellent lectures by Hans Thirring at the University of Vienna gave Viki his first exposure to theoretical physics. But Vienna was not then at the forefront of research. So he took Thirring's advice and continued his studies at Göttingen.

Figure 2: At his retirement celebration in 1974, Weisskopf conducted a chamber orchestra in a performance of Bach's *Brandenburg Concerto No. 3*. Earlier in the program he performed at the piano.

Viki arrived in Göttingen, the mecca of quantum mechanics, in 1928 and became a doctoral student of Max Born. By that time, nonrelativistic quantum mechanics had already demonstrated its power in atomic physics--so much so that Paul Dirac quipped that it would explain all of chemistry and most of physics. In 1928, Dirac published his pivotal extension of the Schrödinger wave equation to relativistic phenomena. The Dirac equation, in combination with Dirac's quantum theory of the electromagnetic field, published the previous year, gave birth to quantum electrodynamics. Despite some striking early successes, QED was soon beset by deep technical and conceptual problems, which placed it at the very frontier of physics. It would take half a dozen years to make QED understandable, and two decades to develop it into a reliable theory. Viki was to play a large role in those efforts.

The natural width of spectral lines was the first unsolved problem that Viki attacked. He produced the solution himself for the case of energy levels that only decay to a stable state and, in collaboration with Eugene Wigner, he extended the theory to all types of transitions.[1] His doctoral thesis in 1931 described the application of that theory to resonance fluorescence.[4]

A remarkable postdoc

In the years 1931-37, Viki had the most remarkable of postdoctoral careers, first with Werner Heisenberg in Leipzig, then with Erwin Schrödinger in Berlin, Niels Bohr in Copenhagen, Wolfgang Pauli in Zürich, and then Bohr again. This history speaks not only to how Viki's talents and promise were judged by the leaders of theoretical physics, but also to the scarcity of long-term positions during the Great Depression. The job shortage was greatly exacerbated for Viki by the exclusion of Jews from the relatively large number of academic posts in Germany after the Nazis came to power in January 1933.

During his postdoc period, Viki developed close friendships with many young colleagues who were rapidly becoming prominent, especially Patrick Blackett, Felix Bloch, Hendrik Casimir, Max Delbrück, Rudolf Peierls, and George Placzek (see figure 4). And on Viki's second day in Copenhagen, in 1932, he met Ellen Tvede, who was soon to be his wife. Ellen became his constant companion until her death in 1989.

Two central problems of QED were the focus of Viki's research during this period: the role of antiparticles and the self-energy of the electron. The negative-energy solutions of Dirac's relativistic wave equation had, after some false starts, led Dirac in 1931 to propose that those states are filled by electrons in accordance with the Pauli exclusion principle, and that any unfilled states, or holes, would appear as positively charged particles with the mass of the electron. Such particles were, in fact, discovered in cosmic ray experiments the following year, but whether they were indeed Dirac's anti-electrons was questioned by no less than Bohr and Pauli. Furthermore, when QED was applied to the self-energy problem, it produced terribly divergent integrals.

Figure 3: Professor Max Born (right) and fellow student Maria Goeppert with Weisskopf in Göttingen, circa 1929.

The understanding of both these problems was greatly advanced in two papers Viki wrote during his two years as Pauli's assistent in Zürich. At Pauli's suggestion, he used hole theory to do a perturbative calculation of the electron's self-energy. Viki made a sign error, which was quickly pointed out by Wendell Furry. When that correction was taken into account, the result was a self-energy that diverges logarithmically as the electron's radius tends to zero.[5]

This was an astonishing result. Classical electrodynamics was long known to produce a linear divergence, and QED had recently been shown to yield a quadratically divergent self-energy if the Dirac equation is taken to be the description of a one-particle system. But Viki was disheartened by having made the error in the calculation; it aggravated his lack of mathematical self-confidence. This insecurity was to plague him again later, in his calculation of the Lamb shift.

The second Zürich paper, written with Pauli, dealt with the quantization of scalar fields.[6] At the time, this work was viewed as a purely theoretical exercise, because no "elementary" spin-zero particle was known. It was, however, an exercise that taught an important lesson, because it demonstrated that antiparticles are not a peculiarity of Dirac's theory for spin-1/2 fermions. They are also an inevitable feature of a quantum field theory of charged bosons.

Furthermore, the Pauli- Weisskopf paper demonstrated that a marriage of relativity and quantum mechanics does not require spin 1/2, as many physicists had incorrectly inferred from Dirac's theory. And with the advent of Hideki Yukawa's meson theory of nuclear forces, the scalar field theory became more than a setting-up exercise for theoreticians.

In 1936, during his second stay in Copenhagen, Viki published a classic paper on vacuum polarization by a uniform electromagnetic field of arbitrary strength.[7] Although the topic had already been studied, the earlier work was very formal and marked by ambiguities. This investigation, the technically most sophisticated of Viki's career, largely cleared up these ambiguities. Especially noteworthy was his prescient recognition of charge renormalization. He exploited the analogy with a charge placed in a polarizable medium to conclude that vacuum polarization produces an unobservable constant (though infinite) factor that multiplies all charges and electromagnetic field operators.

Getting away

By 1936, it had become clear to Viki that an Austrian Jew had better leave Europe, preferably for the US. But that was far easier said than done. There were hardly any positions available in the US, or elsewhere for that matter, and many outstanding physicists who anticipated a Nazi onslaught were competing for them. To further his chances, Viki decided that he should publish something on nuclear physics--the new rage--and do it in English. He carried this off brilliantly with an original application of statistical mechanics to the evaporation of neutrons from nuclei, and published his results in the Physical Review.[8]

Viki's first opportunities to leave came from the Soviet Union: a professorship in Kiev and a senior research position in Moscow. In late 1936 he and Ellen visited Russia and promptly realized that the political climate there had deteriorated drastically since his earlier visit. He would, therefore, only consider a position in the USSR if nothing else was available. In those years, Bohr went regularly to England and America to "sell" the refugees in his institute. In 1937, Bohr convinced the University of Rochester to offer Viki a poorly paid instructorship, which he accepted.

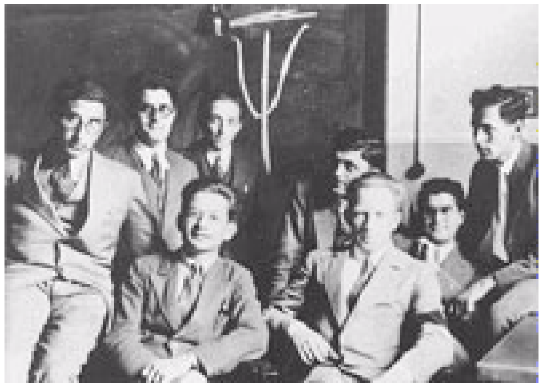

Figure 4: Werner Heisenberg and protégés at Leipzig University in 1931. In front are (left to right) George Placzek, Rudolf Peierls, and Heisenberg. In the back are Giovanni Gentile, Gian Carlo Wick, Felix Bloch, Weisskopf, and Fritz Sauter.

After Viki arrived in Rochester, nuclear physics became a major focus of his research. His studies of Coulomb excitation[9] and radiative transitions[10] were especially noteworthy. He also continued to work on QED and published a remarkable paper addressing the electron self-energy problem in greater detail. Particularly significant was his proof that the self-energy diverges logarithmically to all orders in perturbation theory.[11] This paper strengthened his 1934 result.

Nuclear fission was discovered in Berlin in December 1938, and, nine months later, Germany invaded Poland. Nuclear physics was suddenly transformed from an esoteric intellectual pursuit into a potentially decisive factor in the war. Not being a US citizen--indeed an "enemy alien" until 1943--Viki could not participate in secret war-related work until Robert Oppenheimer asked him to come to Los Alamos in early 1943.

At the time, no experimental data were available for many of the processes involved in a nuclear explosion or the ensuing effects. The Manhattan Project had to rely on theorists for guidance on many fronts. Viki became a prominent member of the theoretical-physics division. In recognition of his ability to quickly devise qualitative solutions to physics problems, Viki's office became known as "the seat of the oracle."

Hans Bethe, the head of the theory division, eventually needed support in running his expanding team and appointed Viki as his deputy. Because Viki took charge of the calculations concerning the effects of the bomb, he was one of the few theorists to witness the Trinity test in the New Mexico desert in July 1945. One month later, the war came to an abrupt end with the nuclear bombing of Hiroshima and Nagasaki.

Back to academia

In 1946, Viki joined the MIT faculty. With his student Bruce French, he revisited the self-energy problem to explore a suggestion by Hendrik Kramers. Kramers had pointed out that what is actually observable is the energy difference between free and bound states of an electron. This difference, he argued, might not be bedeviled by a divergence, but would yield an unambiguous result. Viki and French did not, however, pursue this idea with sufficient dispatch to have a result before the Lamb shift was discovered. In June 1947, Willis Lamb announced that microwave techniques developed during the wartime radar project had enabled him to study the n = 2 levels of hydrogen with unprecedented resolution, and that the spectrum disagreed with the Dirac equation.

Many leading theorists pounced on this discrepancy, and Bethe quickly showed that Kramers's idea led to a level shift close to what Lamb had measured. Bethe's calculation, however, used a nonrelativistic description of the electron, with an energy cutoff (at $m_e c^2$) of the logarithmic divergence to represent uncalculated relativistic contributions that were presumed to provide convergence. French and Weisskopf, in 1948, were the first to complete a consistent calculation of the Lamb shift. But Viki would not publish this result, because it had a very small disagreement with the calculations of Richard Feynman and Julian Schwinger, which were in agreement. Viki could not believe that his work with French was correct. Surely, he thought, the two young geniuses, who were using their new and much more powerful techniques, had not both made the same mistake. But they had!

The upshot was that French and Weisskopf published their year-old correct result only in 1949, a few months after the paper of Lamb and Norman Kroll appeared with essentially the same calculation.[12] The Kroll-Lamb theory paper contains what is, perhaps, the most succinct statement about Viki's place in the firmament of theoretical physics: "[Our] calculation," they wrote, "[is] based on the 1927-34 formulation of quantum electrodynamics due to Dirac, Heisenberg, Pauli, and Weisskopf."

Viki often derided his own technical abilities in theoretical physics. He once said that he was contributing his "don't know how" to a collaborative effort. But he was justifiably proud of his remarkable ability to arrive at results by intuition, by exploiting basic principles and making educated guesses. In that regard, he used to express his gratitude to Paul Ehrenfest, who had been a charismatic visitor to Göttingen when Viki was a student. But, like other masters of the intuitive argument, Viki acquired his magical ability by having devoted his youth to technically difficult calculations. As with great pianists who can improvise so effortlessly, an enormous amount of hard, tedious work lies behind the magic.

Nuclear physics, not QED, was Viki's primary focus during the postwar period. For that work, he found the perfect collaborator in Herman Feshbach. Together, and with students and postdocs, they published a series of papers on nuclear reactions that are noteworthy for the clarity, plausibility, and simplicity of their assumptions.[13] In addition to his own research, Viki produced his *magnum opus*, the treatise on nuclear physics written in collaboration with John Blatt.[14] This textbook became the bible for several generations of nuclear theorists.

Viki's most influential paper of the postwar period was written with Feshbach and Charles Porter.[15] Called the cloudy-crystal-ball model, or just "Feshbach, Porter, Weisskopf," it describes the total and elastic scattering cross section of neutrons (averaged over individual resonances) by a seemingly incompatible blend of the single-particle shell model and Bohr's concept of the compound nucleus. The idea is that, for a time, the incident neutron retains its identity and exists in the single-particle shell-model state appropriate to its excitation before either losing its individuality, as in Bohr's picture, or escaping the nucleus. That approach describes a vast range of data remarkably well. With a masterful mixture of qualitative and quantitative arguments, Viki and Francis Friedman explored the extent to which the single-particle and compound-nucleus pictures are compatible.[16]

CERN director-general

By the late 1950s, Viki was at the apex of his research career. In 1960, he served as president of the American Physical Society. The following year, his appointment as director-general of CERN suddenly transformed him from an academic research scientist heading a handful of colleagues and students into the chief executive of a young and burgeoning multinational enterprise.

Having seen Oppenheimer succeed in a similar if much more dramatic metamorphosis, Viki saw fit to tell the CERN Council in his "job interview" that he had no administrative experience. "But," he added, "I consider this my strength." Apparently it was, for he proved to be an inspiring and imaginative leader of the laboratory, and a skillful diplomat in the complex political setting within which CERN is governed and funded.

Figure 5: Weisskopf, circa 1960. (Photo courtesy of Gloria Lubkin.
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When Viki took over, CERN had a successful research program in nuclear physics with its synchrocyclotron, but only the beginnings of a high-energy physics program. Envisioning CERN as a world-class high-energy-physics laboratory, Viki in his first address to the council, outlined plans for the innovative Intersecting Storage Rings (ISR), to be fed by the proton synchrotron, and he also spoke of a future 300-GeV proton accelerator.

During Viki's tenure as director-general, the number of CERN staff and participants more than doubled to 2500. The laboratory began to make major discoveries, such as pion beta decay and the first high-precision measurement of the muon's anomalous magnetic moment. At the proton synchrotron, radio-frequency separators were installed to produce intense high-energy kaon beams. The proposals for the ISR and the 300-GeV machine led to the formation of an internal committee to assess accelerator priorities and costs; that committee grew into the European Committee on Future Accelerators. In December 1965, as Viki's term as director-general came to an end, the CERN Council approved construction of the ISR and R&D funds for a 300-GeV accelerator.

At CERN, Viki is also remembered for his down-to-earth seminars on particle theory for experimental physicists. A significant factor in his decision to seek the CERN position had been his wish to learn particle physics--a rather extravagant scheme to satisfy so modest a desire, but quite typical of him. This motive charged his many educational activities at CERN with a contagious enthusiasm.

Viki's controversial championing of the ISR, the world's first proton-proton collider, and his advocacy of the 300-GeV machine, set the tone and spirit of European high-energy physics as a serious competitor to the US, with long-lasting significance for physics everywhere. After returning from Europe, Viki recommended the formation of the High Energy Physics Advisory Panel (HEPAP) to the Atomic Energy Commission (later the US Department of Energy). Viki became the first chairman of this influential panel.

Returning to MIT in 1966, Viki served as department chair for six years, and engaged in intermittent research on particle physics with junior colleagues. Numerous honors came his way--the National Medal of Science (1980), the Wolf Prize (1982), the Public Welfare Medal of the National Academy of Sciences (1991), and many honorary degrees and foreign memberships in prestigious academies. He served for four years as president of the American Academy of Arts and Sciences during a crucial period of consolidation. Along the way, he authored a number of books and collections of essays, including his fascinating autobiography, The *Joy of Insight*.[3] The two-volume work *Concepts of Particle Physics*, written with one of us (Gottfried),[17] had its origins in popular lectures to summer students at CERN.

Concerned scientist

The threat to humanity posed by nuclear weapons was a preoccupation of Viki's ever since he participated in the discussions initiated by Bohr at Los Alamos before the Trinity test. After the war, Viki was among the Manhattan Project scientists who organized what became the Federation of American Scientists. At that time, he was also a member of the small committee, chaired by Albert Einstein, that sought to inform the public about the bomb. In the 1950s, Viki participated in the first Pugwash meetings between Western and Soviet nuclear scientists, and he continued thereafter to reach out to influential Soviet scientists in pursuit of nuclear arms control.

Viki joined the Union of Concerned Scientists when it was founded in 1969 in the MIT physics department, and he later became a member of its board of directors. After his election to the Pontifical Academy of Sciences in 1975, Viki played a central role in convincing Pope John Paul II to speak out repeatedly against the nuclear arms race.

A sketch of Viki that is confined to his career, for all its productivity and complexity, would only paint a pale shadow of the man. What was really unique about him was his vibrant personality. He conveyed an infectious happiness. As Viki put it, "I have lived a happy life in a dreadful century!" He had, after all, seen Adolf Hitler and Joseph Stalin in action, and witnessed the first manmade nuclear explosion. He maintained his happy disposition even under difficult circumstances, as when he spent his early months as CERN director in a hospital, suspended in an orthopedic contraption after an auto accident in Geneva.

Viki's almost tangible happiness was not just a signature of his own personality. It was in large measure due to his good fortune in having found two wonderful women to accompany him through life: Ellen, his wife for 55 years and the mother of their two children, Thomas and Karen; and Duscha Scott, who gave him joy and vital support in his final decade.

Victor Weisskopf combined two traits that are usually in conflict and rarely coexist so harmoniously: on the one side, the sentimental and the romantic--on the other, rigorous intellectual discipline and judgment. As he liked to say, his favorite occupations were Mozart and quantum mechanics. He titled his popular and wide-ranging 1963 exposition of science *Knowledge and Wonder*.[18] In giving talks to lay audiences about cosmology, he often played a recording of the deafening crescendo from Haydn's oratorio The Creation that accompanies the words "And there was light." Viki exemplified the vitality and imagination that produced one of history's great intellectual revolutions, and gave it a human face.

An article by Weisskopf that appeared in Physics Today in August 1969 is reprinted on page 48 of this issue.

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