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I.I. Rabi: Physics and Science at Columbia, in America, and Worldwide

The Nobel Prize-winning physicist and internationally renowned statesman of science was a beloved figure on Morningside Heights for more than half a century.

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A familiar problem in history is where to begin. Here our story conjoins the life of an institution with the life of an individual: the former spans two and a half centuries; the latter, a single century-the twentieth. The history of the institution provides a fiducial context for the lives of individuals, but since this is one of many narratives of many unique voices who collectively-with their academic progeny-define, indeed are, the institution, it is on the life of the individual that we focus.

A connecting thread between our individual-I.I. Rabi-and the institution of which he was a part-Columbia University-is from time to time provided by a much larger context: the evolution over the centuries of science in America. Here it should be remarked that the history of Columbia spans the whole history of American science, and the lifetime of Rabi covers the overwhelmingly greater part of its growth.

A Seminal Public Scientist

Benjamin Franklin's autobiography tells us that when "Abbe" Jean-Antoine Nollet (1700–1770), authority on science in the court of Louis XV, "demonstrator" of electrical phenomena to all ranks including the queen and the dauphin at Versailles, and known to a far wider audience as "Preceptor to the Children of France," first had his attention drawn to the writings on electricity of one Ben Franklin of Philadelphia, he refused to believe them. Not only did this panjandrum of science disbelieve the recorded phenomena and their interpretation, which he must have readily perceived as a threat to his own authority and scientific stature, but he denied the very existence of their author. How could an American, living on the perimeter of the untamed wilderness, far removed from European culture, have occasion or opportunity for such arcane philosophy? No! He and his alleged discovery were phantasms, cacodemons invented by Nollet's enemies to torment him (and there was no shortage of enemies in the court of Louis XV).

However, Franklin was real enough; his experiments were soon repeated and his ideas spread widely. His "principles" soon led to the sensational demonstration of the electrical nature of lightning. His name, and "Franklinism," became known to most and familiar to many-statesmen and philosophers, ladies of the court, and scullery maids alike.

With such a glorious and dramatic demonstration of American colonial prowess in electrical science, one might have expected the field to have flourished and spread. However, there was but one Franklin, and American science was destined to be-for a couple of centuries-more the spontaneous efflorescence of individual genius than a widespread cultural phenomenon. However, Franklinism was perhaps a portent of the future. The invention of the lightning conductor to protect buildings was the first practical use of electrical "science"; and the exploitation of Franklin's scientific reputation enhanced the stature of science in the world of politics and diplomacy. Minister Turgot's characterization of Franklin as he "seized the fire from heaven and the scepter from the tyrant's hand" links together, ineluctably, his services to science and democracy.

It is unlikely that the Reverend Samuel Johnson, when he sat down in 1754 to educate his eight students in the liberal arts and sciences at King's College, the predecessor of Columbia, paid much attention to the seminal discoveries in electricity in Philadelphia. Not that Franklin and Johnson were unknown to each other. Franklin knew, and was impressed by, Johnson's work on ethics, had translated the Latin into English, and had tried to secure him as rector for his Philadelphia Academy. Nor were the sciences then ignored or even neglected. The liberal arts inherited from the medieval universities had their quota of these in the quadrivium: geometry, astronomy, arithmetic, and music. And the appointment in 1757 to King's College of the first professor of mathematics and natural philosophy-

Daniel Treadwell-showed a more up-to-date concern. But all this referred to a borrowed culture, distant in time and space, with little ingredient of domestic product. And so it would remain for the first century and a half of Columbia's history.

Scientific Awakenings

During the rapid growth of the U.S. in the nineteenth century-extension of boundaries, agrarian and urban growth, emergent institutions and industries, and rapidly developing political structure-it would have been remarkable indeed if there had been no expression of scientific interest and activity. Outstanding examples of nineteenth-century American scientists were many: Joseph Henry (1797–1878), upstate New York, electromagnetism and telegraphy; Lewis Morris Rutherfurd (1816–1892), Columbia University, optics and astrophysics; Josiah Willard Gibbs (1839–1903), Yale, physics, chemistry, and thermodynamics; Henry Rowland (1848–1901), Johns Hopkins, optics and experimental physics; Albert Abraham Michelson (1852–1931), U.S. Naval Academy, the first American winner of the Nobel Prize for Physics (1907). By the end of the century there was a significant growth of science in industry, especially the new electrical science, and opportunities therein attracted outstanding minds from abroad (Alexander Graham Bell and Nikola Tesla, among others).

Serbian immigrant and Columbia College graduate Michael Pupin 1883C would make significant contributions to long-range telegraphy and telephony-and a sizable fortune. He attributed his success in part to a fortunate encounter with classical academics/mechanics. Inspired by this experience, he preached the study and promotion of "pure science," which he called the "goose that laid the golden egg." He was for many years professor of electrical engineering at Columbia, and when he died, he bequeathed the residue of his estate to "pure science"-as fostered by the newly completed physics building (1927), subsequently named Pupin Laboratory in his honor.

Pupin Laboratory eventually became I.I. Rabi's scientific home, the locus of virtually all his and his collaborators' scientific discoveries. In 1977, Columbia celebrated fifty years of Pupin Laboratory and fifty years of Rabi at Columbia. By then the two had become inextricably associated.

Rabi's Pupin was one of the earliest powerful and fertile American schools of physics. But it wasn't the first U.S. academic research center to match and embellish the traditions of the great research centers of Europe. That distinction surely belongs to Thomas Hunt Morgan (1866–1945) and his colleagues, working in what later became famous as the "Fly Room" in Columbia's Schermerhorn Hall. From this emerged the highly successful American school of genetics of Morgan, H.J. Muller '10C '16GSAS, and others.

Morgan's work was not overlooked in Europe. In an early review of its striking progress, Dutch geneticist Hugo De Vries (as I recall), in a review of the subject, refers to Columbia as a great "sleeping bear on Morningside Hill" which had "stirred and awakened itself" with quite astounding results.

In 1927, at the time of a dramatic breakaway in Europe from the "classical" notions of more than two centuries, Rabi, after a preliminary undergraduate education at Cornell, began his life's work at Columbia.

Rabi and the New Physics

Rabi's Jewish parents came to America from Central Europe in search of a better life, free from bigotry and the menace of persecution. Rabi's path from the crowded, indigent, immigrant life of New York's Lower East Side to its institutes of higher learning lay through the streets and public schools there and later in Brownsville, across the water in Brooklyn.

The education the schools provided may have been minimal, but for the resourceful and the independently minded the opportunities to learn were many. And Rabi found and exploited them. Local schools were run by the "wonderful tough Irish" from whom "you could get trouble if you looked for it," but they "created an atmosphere in which you could learn" if you wanted to.

He discovered the local public library (Carnegie), which "opened a universe" to him, and began a period of omnivorous reading. He began alphabetically on the library shelf with "A," and the new world of astronomy, the Copernican system especially, was a veritable epiphany of scientific enlightenment. There were equally profound lessons to be learned outside the library. As far as frugal resources allowed, Rabi immersed himself in a variety of activities at home-in the miracle and mystery of radio, in the variegated manifestations of nature evidenced through gardening, and in some down-to-earth photography.

Rabi, like many young immigrants of his day, lived in two worlds: one that he was leaving, that of the traditional customs and beliefs of his parents' home; the other, that he was vigorously exploring for himself, of the artifacts, phenomena, and people outside. He recalls an amusing and characteristic effort to bring the two worlds together. On the occasion of his Bar Mizvah, he addressed the gathering of family and friends on the subject "How an Electric Light Works" in Yiddish.

Already in Rabi's school years, science was becoming central to his outlook. His early resolve to determine his own future was manifest in his decision to continue his education not at Boy's High School "where all the smart Jewish boys went," nor at a yeshiva, as his parents suggested, but at the Manual Training High School in Brooklyn. However, science was not his only concern: he shared the characteristic immigrant determination to become a "good American." In his school-leaving Regents examination in 1916, Rabi placed first in history.

As he moved from Brooklyn's Manual Training School to the arena of front-line science, Rabi was again determined to find his own way, by trial and error if necessary. Of the opportunities available, he chose Cornell "with a sense of freedom and novelty," enrolling initially as a student of electrical engineering. Later he was attracted to and challenged by a course in analytical chemistry, which seemed to bring him closer to what he felt intuitively to be the intimate or ultimate structure of matter. At this time, the relationship between physics and chemistry was undergoing drastic change with respect to the study of the constitution of matter, which textbooks of the period would have reflected. For several years, then, Rabi was a chemist in embryo, actually discovering that the part of chemistry that really interested him was called physics. (How far was the distinction one of conventional definition?)

Despite a glowing testimonial from chemistry professor A.N. Brown, Rabi was not awarded a fellowship that would have enabled him to stay on at Cornell to study physics. Influenced in part by his future wife, Helen Newmark, Rabi decided in 1923 to become a graduate student at Columbia. He obtained a paying job as part-time tutor in physics at City College, New York: sixteen classroom hours of teaching a week with a stipend of $800 per annum. For the next two years, Rabi combined the demands of teaching at City College with his doctoral studies and research at

Columbia. Additionally, he undertook the task of teaching himself (with a few fellow graduate students) the "new" physics-quantum mechanics-which was emerging with breathtaking speed and vigor in Europe but in which no American professors at Columbia were able to provide instruction or guidance.

Rabi accomplished everything in his own characteristic style. His instructional duties at City College were somewhat relaxed, and he managed to keep the demands of Columbia's graduate physics courses to a minimum. For his own research-the magnetic properties of crystalline Tutton salts, a topic inspired by English visitor W.L. Bragg's seminar-he developed an ingenious experimental procedure that obviated much of the tedious routine preparation and measurement of a more conventional approach.

Incidentally, Rabi's experimental approach came serendipitously from his reading of classical literature-in much the same way Pupin's inspiration came suddenly from J.L. Lagrange's *Mécanique analytique* (1788), which he had, some forty years earlier, picked up by chance from a secondhand bookstall on the banks of the Seine in Paris. In Rabi's case the work in question was J.C. Maxwell's *Treatise on Electricity and Magnetism* of 1873. These are two examples of Pasteur's famous maxim that fortune favors the prepared mind.

Rabi devoted his Sundays to self-education. He organized a group to study the new physics with fellow graduate students Francis Bitter, Ralph de Kronig, S.C. Wang, and Mark Zemansky (all of whom became notable physicists). They met weekly, spent the day together talking, arguing, devouring and digesting the latest European journals, learning, and eating. Such was their devotion and infectious enthusiasm that in due course they were joined in their marathon sessions by some *professors* from New York University. (Not surprisingly, when Rabi later met his counterparts at leading German universities, he found that notwithstanding his own lack of formal instruction by the great "masters," he was better prepared for research than were 95 percent of the German students.)

For Rabi and his fellow students it did not suffice to study, follow, and understand the work of others. The real test of understanding was to solve a problem of their own. They chose the application of Erwin Schrödinger's wave-mechanical equation to the symmetrical top. The mathematics was formidable, but serendipity once again came to the rescue, this time in the work of nineteenth-century mathematician C.G.J. Jacobi. De Kronig and Rabi's work on the quantum mechanics of the symmetrical top was accepted for publication in the February 1927 American *Physical Review*.

In July 1926, Rabi had completed work for a Ph.D. and successfully submitted his thesis for publication in the *Physical Review*. The following day he and Helen Newmark were married. In May 1927, he was awarded a Barnard Fellowship ($1,500 a year for two years), enabling him to do what he had set his mind on-complete his scientific apprenticeship in Europe.

In June 1927, Rabi resigned his appointment at City College, and in July he embarked for Europe. His destination was uncertain; he had no formal plans. Unannounced, he arrived in Zurich, hoping to meet and work with Schrödinger. But Schrödinger was just leaving Zurich to succeed Max Planck in Berlin. So Rabi changed course for Munich, home of pioneer of quantum mechanics and celebrated teacher Arnold Sommerfeld-a thoroughly European professor with an academic style not entirely to Rabi's taste.

A side trip to an annual British Association meeting in Leeds, England, provided Rabi with an opportunity to see and hear many of the greats, especially Peter Debye and the already renowned young Werner Heisenberg. He joined Helen Rabi in London, and they traveled to what was rapidly becoming the physicist's "shrine"-the Niels Bohr Institute in Copenhagen. Rabi may have been mystified and awed in the Bohr presence, but this was no basis for a lengthy association. In any case, Bohr had arranged for Rabi to go to Hamburg to work with Wolfgang Pauli (1900–1958), whose reputation as an acerbic theoretical physicist and a sharp critic was second to none.

After a few weeks in Copenhagen, the Rabis settled in Hamburg. Pauli's piercing arguments did not faze Rabi; he probably enjoyed the test of his mettle. And in Hamburg, it turned out, there was another attraction, the eminent experimental physicist Otto Stern (1888–1969), whose personal style and modus operandi Rabi would find most congenial, and whose influence would have a profound effect on his future.

Tickling a Molecular Beam

Stern had recently (1921–1923) completed and published his already celebrated molecular-beam experiment demonstrating the phenomenon of "spatial quantization." The "Stern-Gerlach" effect was utterly perplexing from a "classical" viewpoint but a "natural" outcome of the quantum mechanical principles. This was the kind of issue that Rabi and his fellow students had sought to understand at the Sunday seminars at Columbia. Now here he was-by accident-at the very source, the fountainhead, of the latest in science. Stern's laboratory-which was composed of a group of some half-dozen students and associates, quite substantial in those days-became more than a distraction from Rabi's arranged program of theoretical work with Pauli. In true Rabi spirit, it was not enough to watch, listen, and learn passively; he wanted to get his hands on the business.

In the canonical Stern-Gerlach experiment, the streaming (sodium) atoms are deflected in their path by the influences of a non-uniform magnetic field. Rabi argued-by analogy to the passage of light through a prism-that if the atomic beam were to pass at a glancing angle into a uniform magnetic field, then this deflection would be different for different effective magnetic moments (that is, different orientations of the atom's axis). In mentioning this idea to Stern, the prompt and generous response was "Why not try the experiment here?"

Ironically, Rabi had come to Europe to learn theoretical physics. Now he was being invited to mount his own experimental project. Quite an honor, especially for a visiting American-and an irresistible opportunity to try a new variant of the Stern-Gerlach experiment in Stern's own laboratory. In 1928, the equipment was made ready with much help from a fellow visitor to Stern's laboratory, John Taylor from Scotland. The experiment was completed successfully, and the work was published in *Zeitschrift für Physik* in German and, in a shorter version, *Nature*. The strenuous exertions as self-taught students at Columbia had reaped a good harvest in Germany.

In Hamburg Rabi heard quite casually an echo of the old theme: American science and physics were, at best, marginal. Browsing in the departmental library, he went to look at the latest happenings at home as reported in the *Physical Review*. The current monthly numbers were nowhere in sight. On inquiring at the librarian's desk, he was told that the Hamburg library had arranged to have the individual numbers of the journal collected and sent to Germany as a single package to economize on postage. In any event, he was assured, the delay was not important because "not much of great significance is published in the *Physical Review*."

Rabi's own success in Hamburg assured him that this attitude would soon be proved false. Numerous encounters with fellow students, visitors from America bent on similar paths of enlightenment, confirmed this view. They demonstrated that American physicists (or at least those who visited Germany) were a match, or more, for their German counterparts. And in Hamburg, the style of the Americans-their informality, lack of strict and regular hours, uninhibited expression of joy, anguish, or frustration in their work-had attracted attention and comment that "the American work method was, apparently, successful"; it might even be emulated.

After the experimental success in Hamburg, Rabi turned his attention to what was, ostensibly, his primary goal-enlightenment in theoretical physics. This took him early in 1928, again unannounced, to see Heisenberg in Leipzig. Heisenberg was preparing to leave Leipzig for an extended lecture tour in America, and the visit lasted just long enough for Rabi to make himself known and, apparently, to make a good impression, as subsequent events revealed.

Pauli had left Hamburg for a chair in Zurich. So Rabi went to Zurich once again in March 1929. There he found quite a galaxy of physicists, both European and American, attracted no doubt by Pauli's presence. They included Paul Dirac from Cambridge, Walter Heitler from Germany, Fritz London, Leo Szilard and Eugene Wigner from Berlin, John von Neumann from Göttingen, and Wheeler Loomis, J. Robert Oppenheimer, and John Slater from the U.S.

Nearing the end of his European *wanderjahre*, Rabi was enjoying the exhilarating air of the Swiss Alps and the stimulating society in Zurich. Heisenberg, meanwhile, was away in the U.S., helping to shape Rabi's life in a most dramatic way. On a visit to Columbia, Heisenberg met George Pegram '29HON, chairman of physics, who had, in 1929, written to the leading theoretical physicists soliciting suggestions for a suitable professional appointment at Columbia. Heisenberg pointed out that Columbia already had an eminently suitable candidate of its own: I.I. Rabi.

Immediately Rabi received a cable offering him a lectureship at $3,000 per annum. He accepted promptly, and on August 1, 1929, he set sail for the U.S. and Columbia. Although the appointment was, implicitly, as a theoretical physicist, Rabi had already tasted the pleasures of experimentation both at Columbia and in Hamburg. When Pegram encouraged him to "at least direct some experimental work" Rabi began to actively contemplate such possibilities. In later years, Rabi lightly evaded the classification theoretical or experimental and declared himself "just a plain home-grown physicist."

Rabi devoted his first year at Columbia as lecturer exclusively to a strenuous effort to bring the graduate-student instruction up to date-to distribute some of the European bounty he had brought back in his lectures on quantum and statistical mechanics. Plans for experimentation were latent, nursed but not neglected.

In the 1920s, in Hamburg and elsewhere, the frontier of physics was in the atom and the new world of quantum mechanics that its study begot. But a new frontier lay ahead: the terra incognita of the atomic nucleus. To Rabi, on the threshold of his physics odyssey, the notion of combining the sophistication of quantum mechanics with the unexplored territory of the nucleus would have been irresistible. The molecular beam technique seemed to have possibilities far beyond the limited explorations in Stern's laboratory-and it held a greater appeal for Rabi than the high-energy, atom-smashing attack on the nucleus that was soon to emerge. Rabi found it more appealing and more sophisticated to gently tickle a beam of molecules. In any event, the material resources for the molecular beam technique were more practically realizable than the high-energy accelerator alternative. Rabi did not relish the task of coaxing from a departmental chairman or dean even the relatively modest funds needed for molecular beam equipment.

Urey's Beneficence

Again, fortune smiled-this time, in his association with an institution in which the university spirit of a "community of scholars" at times prevailed. Among Rabi's colleagues was the brilliant professor of chemistry Harold Urey '46HON (1893–1981), who demonstrated (working in Pupin Laboratory) the existence of a heavy isotope of hydrogen of mass 2 (deuterium). In recognition of this achievement, for which he won the Nobel Prize in 1934, Urey received an award from the Carnegie Foundation of about $8,000 to assist his research. Urey had no immediate need of this munificence, and in the course of a not-infrequent lunchtime meeting with his colleague Rabi, Urey asked if he could use some part for his research. For Rabi this never-to-be-forgotten act of generosity made possible the realization of his experimental plans, which he now began in earnest and which, for the next decade or so, flourished like the proverbial bay tree.

All that is possible here is to indicate a few salient features of the original Stern-Gerlach demonstration of quantum-mechanical atomic behavior. In the original experiments, magnetic forces acted directly on the atomic electrons. Optical spectroscopy, pushed to the limits of refinement, could show that atomic nuclei possess quantum-mechanical angular momentum and associated mechanical properties. The coupling between nuclear and atomic components indicated that proper understanding of those properties, and experimental investigation of atomic interactions, could reveal precise information about the nucleus-even though nuclear magnetic moments were some three orders of magnitude smaller than those of the electron.

Shortly after Rabi returned to Columbia, he set up a joint seminar with Gregory Breit (1899–1981), his colleague at New York University, to explore and discuss atomic-nuclear phenomena. One of the early fruits of this enterprise was their seminal theoretical paper (1931) exploring the variety of atomic-nuclear behavior in magnetic fields over a wide range of strengths. In the experimental molecular-beam technique subsequently developed, a first separation would spread out the individual discrete quantum-mechanical component states, and then they could be individually subjected to known mechanical forces. Finally, the resulting beams could be recorded and analyzed.

For the next few years in the mid-1930s, Rabi and his growing group of disciples and co-workers were intensely absorbed in studying atomic-nuclear-molecular beams of their own creation. They were beginning to determine atomic-nucleus properties at a surprisingly vigorous rate. The brisk pace was essentially self-determined because they were not threatened by any immediate competition. The course of events in Germany had all but destroyed the Hamburg group. Otto Stern-Rabi's own mentor-was now a refugee from Nazi barbarity, living and working in Pittsburgh.

As Rabi and his colleagues refined their experimental techniques, and as the new results accrued, so did intuitive insights into the paradoxical quantum-mechanical features. One intriguing possibility was to go beyond observing the quantum-mechanical transitions incidental to the atomic passage through the various magnetic fields-to actively induce such transitions by imposing a (radio-frequency) oscillating field in addition to the (static) magnetic ones. A visit to the molecular-beam laboratory in 1937 by C.J. Gorter of Groningen precipitated active exploration of such techniques. Gorter had already attempted unsuccessfully to detect such transitions, not in the refined context of molecular beam experimentation but more simply in aggregate bulk matter.

Within days of Gorter's visit, work was begun to modify a molecular-beam apparatus to test out the new so-called NMR (nuclear magnetic-resonance) technique. Within a few months, there were lively celebrations by the team of Rabi, Sidney Millman '35GSAS, Jerrold Zacharias '26C '33GSAS, and Polykarp Kusch '83HON, with all students and research associates joining in the festivities. A new chapter in atomic-molecular spectroscopy had been opened-one of extraordinary precision and refinement.

Prior to the success of NMR, physicists had tended to view the changes taking place in the space-quantified orientations of electrons in nuclei in terms of the arcane quantum mechanics of such dynamics. But soon a more general viewpoint prevailed: a "spectroscopic" transition between two quantum-mechanical states with the absorption of a quantum of the corresponding electromagnetic radiation of correct ("resonant") frequency. In contrast to the time-honored optical spectroscopy (of visible light), the new NMR frequencies were one hundred million times smaller-and the two quantum-mechanical energy states were now separated by the correspondingly smaller energy. A new range of phenomena was now accessible to exploration and measurement with unprecedented exactness and sensitivity.Rabi was elated-not least because he had helped demonstrate, with éclat, that American physicists had now come of age and were of full stature alongside those of Europe. Who now would trivialize the contents of the *Physical Review*? And Rabi himself, after a decade of intense work, had fully vindicated the trust and confidence of Stern, Heisenberg, Pegram, and Urey. He had realized the aspirations of Pupin at Columbia. American physics had found its leadership, and Rabi and Columbia were prominent at its center.

Columbia's Radiation Lab

The power of the new sophisticated technique soon demonstrated itself in its application not simply to atoms but to cases in which fundamental principles were tested. To do so, physicists turned to the simplest system in which the particulars were considered well known. In atomic nuclear physics, this meant the hydrogen atomic system-one electron and one proton-or one heavy-hydrogen atom, where complexity would least obscure principle.

The Second World War diverted most scientific efforts from these lines of investigation. However, there were some quite remarkable early discoveries. Only seven years earlier in Pupin, Urey had demonstrated the existence of the heavy hydrogen isotope "D." Now with the powerful NMR technique, Rabi and his colleagues determined the shape of the D nucleus and its surprising departure from sphericity (the "electrical quadruple moment"). What could be a more apt recognition of Urey's magnanimity of 1934? Again it was a clear example of the rapid ascent to prominence of American basic research in physics. For Rabi personally, there was a sense of religiosity ("nearer to God") in these deepening investigations, perhaps complementing the traditions of his early home and youth.

In the late 1930s there were dark clouds over Europe. For American scientists, there were also messengers who related the dire news-eminent refugee scientists who had escaped from Europe. Enrico Fermi came to Columbia, H.A. Bethe to Cornell, Felix Bloch to Stanford, George Gamow to Washington, D.C., and Rabi's mentor from Hamburg, Otto Stern, was in Pittsburgh. By 1940, the sweep of the Nazi blitzkrieg over Western Europe and the perilous, isolated position of England fully revealed in the Battle of Britain had begun to stir U.S. support, particularly among scientists. Developments in aerial, sea, and submarine capability revealed that the Second World War would be far more technological than previous wars. There was a clear appeal to the brains and skills of scientists as well as to their sympathies. The events in Europe were also a warning of what might befall the U.S. if it were swept into war ill prepared.

The sympathy of many U.S. scientists, which now included a significant proportion of refugees from Nazi fascism, was undoubtedly with Great Britain and what remained of its allies. In principle, the industrial-technological might and scientific expertise of America was a formidable potential if it could be put to use-in the spirit of Churchill's plea, "Give us the tools and we'll finish the job." By 1941, there was a major political response: "Lend-Lease," an agreement that while remaining technically neutral, the U.S. would lease military equipment to Britain and provide other aid.

However, months earlier, the scientific community faced the problem of how best to bring its potency to bear. The crisis brought forth the latent power of American science-and the leadership to direct it. Rabi, though newly arrived at the forefront of American (and world) science, took up the challenge, and in the two or three succeeding war years he emerged as a foremost statesman of science. This was quite a different sort of "scientific" leadership from that which the neophyte

American scientist wandering through Europe had yearned for. However, it was a leadership that in the near future would be sorely needed.

Rabi's-and Pupin's-wartime transformation was swift and effective. In November 1940, Rabi closed down his molecular beam laboratory in Pupin and transferred his energies to radar development. With equal dispatch, he toured the country, coaxing his fellow physicists to join the new radar laboratory located at MIT (the "Rad Lab"). Rabi's talents, personal charm, and persuasiveness-as well as his scientific stature and integrity-were of inestimable value in the rapid establishment of "Rad Lab" and its role in the development of radar and other technologies as powerful tools in the military armory.

From late 1940 to 1945, Rabi was formally associate director and director of research, but his energies and influence extended far beyond the immediate scientific and technical realms. Formerly, his aim was, in his phrase, "to get closer to God"; now it was to close in on the Devil himself, to destroy Nazism and all its works.

To this end, the scientific community needed close, effective cooperation with the U.S. military. However, in view of their differing traditions, it was inevitable that there would be confrontations. It was not in Rabi's nature or in that of many scientists to simply serve the military as a hired technical aide. He could not accept the idea expressed by some higher military echelons that "scientists should be on tap, not on top." Rabi's aim was partnership with the military, the sharing of goals, and in his sphere, Rad Lab and radar, he was eminently successful. In his words, "When we got to know one another, when they (the military, specifically the navy) learned we were trying to help them and that we respected them, when they discovered that we didn't want any of the glory, we came to be friends, with mutual respect."

Cooperation with the military was outstandingly successful. At the end of 1941 there were only a handful of scientists and little data on radar to work with. Within a couple of years, however, the few radar novices had grown to a mighty force of several thousand. In cooperation with the armed forces and industry, they designed, tested, set up for manufacture, and by war's end there were some 20,000 "3cm" radar systems in service. The technology was indispensable. In fact, military operations of any significant scale without radar had become unthinkable.

At the same time, Rabi's molecular-beam laboratory redirected its efforts entirely from atomic-magnetism to radar-magnetrons-the generators of microwave radiation at the heart of radar equipment. Stalwarts from the former molecular-beam laboratory-J.M.B. Kellogg, Sidney Millman, and Polykarp Kusch-were the mainspring of the work, a modern version of plowshares to swords. This auxiliary radiation laboratory, the Columbia Radiation Laboratory, supplied some invaluable basic scientific support for the main radiation laboratories at MIT. The Columbia Radiation Laboratory continued in existence at the war's end. Fittingly enough, its research work resulted in a fundamental reassessment of the basic science of electromagnetism-atomic quantum physics: the same electromagnetism that provided the basis for the sophisticated, elaborate technology represented by radar.

There were many major discoveries, such as the anomalous magnetic moment of the electron by Polykarp Kusch (with H. Foley) in 1947, which received the Nobel Prize in 1955; the fine-structure of the hydrogen spectrum by Willis E. Lamb (with R.C. Retherford) in 1947 (Nobel Prize in 1955); and microwave molecular spectroscopy, leading to the maser and laser, by C. Townes '63HON et al. in 1953 (Nobel Prize in 1964). By the mid-1950s, American physics was, in general, leading the world-and Columbia-Pupin was at the forefront.

Skepticism About the Bomb

In 1939–1940, Columbia was already the locale of seminal activity that expanded into the awesome development of the atomic bomb. Enrico Fermi had escaped to Columbia from Mussolini's Italy; together with Urey, John Dunning '34GSAS, and visitor Leo Szilard, they were the inspiration and moving spirits in this effort. (Einstein was briefly but crucially drawn into the struggle.) After a couple of years, the project moved to Chicago, but the first federal government money-some $10,000 to find suitable graphite for Fermi's uranium assembly-was a grant made to Columbia.

Rabi was not directly involved in this historic enterprise, but he was far more than an interested spectator and critic. He was skeptical about the atomic bomb's contribution to the war effort and uneasy about the moral implications of such a weapon of mass and indiscriminate destruction. He also still had essential work to do at Rad Lab.

By 1943, when the United States had committed itself to the atomic bomb, Rabi had matured into an experienced authority on scientific-military-government cooperation. He also had a good rapport with J. Robert Oppenheimer (1904–1967), begun when they had met as fellow Americans in Leipzig in 1929. Oppenheimer was a theoretical physicist from California, newly chosen to be scientific director of the Manhattan Project, and Rabi provided fatherly advice on broad policy matters to his somewhat younger, less-seasoned colleague and friend. Officially, Rabi was throughout a senior consultant to the director. Though a not-infrequent visitor, he withstood efforts to draw him closer into the Los Alamos enterprise.

Rabi was eyewitness to the climactic and terrifying test at Alamogordo, the first atomic explosion, about which he wrote, "A new thing has been born, a new control, a new understanding of man, which man has acquired over nature. That was the scientific opening of the Atomic Age." It was an awesome responsibility for science, conferring a new sense of power and maturity. It also meant a loss of innocence, of childlike curiosity as a basis of scientific endeavor.

Alamogordo 1945 was a unique moment in human history. Locally, it marked a watershed for American science, as scientists who had flocked to enlist in the war effort now returned to take up abruptly where they left off years ago. For some who had participated in the enormous changes of science, the return proved not so simple. Rabi's wartime experience had shown him that stature, influence, and authority-at least over one's own activities-were necessary conditions for effective research and self-satisfaction. He eschewed the need to tangle with red tape endlessly. Spontaneity was his style, and it was possible in an academic setting if he could be manager of his own "show," chairman, for example, of his own department. And this he negotiated with a Columbia administration anxious to welcome him back.

Rabi's immediate task was to rebuild the thriving molecular-beam group. He and his co-workers John Nafe '48GSAS and Edward Nelson '49GSAS resumed the program with a simple hydrogen system with new sensitive and precise techniques. This work, together with Kusch's and Lamb's spectacular discoveries, led to the famous Shelter Island Conference of 1947, an elite gathering of some two dozen of the foremost physicists in the U.S. to review the fundamental implications of the new measurements and discoveries. American-and Columbian-physics was now not only of worldwide status: it was at its very center. This was, in essence, the climax of Rabi's postwar scientific efforts.

Within a few years, Rabi discovered the drawbacks inherent in his privileged position as department chairman. His authority and independence were counterbalanced by the responsibility of having to deal with the problems of others. In 1949 he confessed, "I found that I did not like to run people, to be responsible. The actual details of running the department, the nuts and bolts of it, were not to my taste." He left the decisions to a nominating committee and departed for Europe, passing the baton to Polykarp Kusch.

The period of Rabi's chairmanship had been one of strenuous rebuilding in a very competitive postwar situation. Topflight physicists had become celebrities to be sought and wooed. Rabi left his stamp of quality and style, and a reputation of no-compromise standards for Columbia physics. What mattered was not so much who entered (as students) but who left with the Columbia imprimatur. Rabi referred to this as the mousetrap principle: easy to get in but not so easy to get out-alive!

He was willing to admit on trial anyone with a genuine interest in physics who was willing to work hard, with minimal a priori evidence of the ability to succeed. This policy may have been unpopular in some student circles, but it was vindicated in its wide influence on American academic physics. Many Columbia physics Ph.D.s-those who had passed through the test of fire-were eagerly sought after to fill starting academic roles at other universities. And many were conspicuously successful in spreading Rabi's ideals and standards.

Institution Building: Nevis, Brookhaven, and CERN

Rabi had lasting influence on American science in other areas. Wartime experience had shown forcibly how science could operate on the grand scale. Rabi translated this possibility to the postwar academic scene and suggested academic cooperation of an unprecedented scale. There were like-minded colleagues in the Ivy League sister universities, but individually they were more used to viewing each other in a competitive rather than a cooperative spirit. But Rabi's diplomatic skills and the high esteem in which he was held were more than a match for the difficulties encountered. The first, exploratory discussion between representatives of nine participating universities took place early in 1946. By the end of the year, a site had been chosen on Long Island, N.Y., and in early 1947, in a formal contract between the group- Associated Universities Inc.-and the Atomic Energy Commission, the

Brookhaven National Laboratory was born. It has now passed its fiftieth year of operation.

To build up and maintain a viable, first-class academic department, Rabi was inevitably concerned with the attractiveness of its facilities. High-energy equipment at Columbia itself seemed essential, though it was hardly feasible within the confines of the Morningside Heights campus. The Nevis estate, some twenty miles north up the Hudson River Valley, was enticingly spacious and soon became the site for Columbia's Nevis Cyclotron Laboratory.

From about 1950 to 1970, the Nevis estate was the base for a most vigorous and successful research program, particularly in "meson" (intermediate) physics, a stage in the development of very large-scale high-energy physics. Within a decade or two, this latter had outstripped the scale of any university or local research facility, finally becoming international and then global in scale. And in these developments, Rabi played a key role.

Inspired by Brookhaven, and in the context of his participation as U.S. Delegate in the 5th General Assembly of UNESCO in Florence, Italy, in 1960, Rabi evoked the possibility of a similar European collaboration in a joint laboratory-one beyond the resources of any single country. The European scientists first reacted with ambivalence, even hostility. But with characteristic diplomatic skill, tact, and persuasiveness, Rabi coaxed several leading European scientists to themselves advocate the proposal, with UNESCO sponsorship, and to explore its realization without material support from the U.S. Within a little less than two years, in February 1952, representatives from eleven European countries agreed formally to establish at Geneva the CERN (Conseil Européen pour la Recherche Nucléaire) Laboratory. At that meeting, they sent Rabi their greetings, informing him of the "official birth of the project you fathered in Florence. . . . Mother and child are doing well. . . . "

The 23 cosignatories included Heisenberg (Germany), Niels Bohr (Denmark), Pierre Auger (UNESCO France), Hannes Alfen (Sweden), and Eduardo Amaldi (Italy). Some 25 years later, a vigorous flourishing CERN could be held up as a supreme example of international cooperation in science. And Rabi's reputation as a statesman of science had become legendary. Indeed, when Columbia celebrated "Fifty Years of Pupin Laboratory and Fifty Years of Rabi: 1927–1977," CERN's director, John B. Adams, sent a message sadly regretting his inability to join the gathering in person, declaring that, had he been able to do so, he would have begun, without any implied impiety, with the words "Our Father who art in Columbia..."

In all these efforts to promote the development of science, Rabi was affirming his conviction that cooperation in science provided incomparable opportunities to foster cooperation more widely. He may well have had in mind the sage advice of Ben Franklin: "Don't expect to do good and to get the credit for so doing." (At least not at the same time!)

In 1948, Dwight D. Eisenhower resigned his military position to become Columbia's fourteenth president. At their first meeting, congratulating Rabi on his recent Nobel Prize for Physics (1944), Eisenhower added that he was always happy to see "one of Columbia's employees honored." The remark, it is recorded, drew from Rabi a measured response: "Mr. President, the faculty are not *employees* of the University-they *are* the University." This was, apparently, the beginning of some twenty years of friendship. To Eisenhower, Rabi represented science and its excellence at Columbia. At times, he expressed his anxiety that Rabi might yield to the many temptations to move elsewhere. But Rabi, virtually born and bred a New Yorker, regarded himself as part of Columbia and never seriously entertained leaving.

When, in 1953, Eisenhower left Columbia for the U.S. presidency, Rabi was already influential on the Washington and the international scene. In 1957, faced with the monumental scientific questions posed by the Atomic Age and spurred by the sudden appearance of the Soviet Sputnik, Eisenhower created (or re-created in new form) the office of Special Assistant to the President for Science and Technology (SAPST). Associated with this, and chaired by the special assistant, was the new Presidential Science Advisory Committee (PSAC). At the 1977 Columbia presentations, James Killian (first holder of the SAPST, then president of MIT) and the current incumbent, Frank Press '49GSAS (subsequently president of the National Academy of Sciences), paid tribute to Rabi. And a message from President Jimmy Carter expressed his pride "that both my scientific advisor and my secretary of defense [Harold Brown '45C '49GSAS] were Rabi's pupils-influenced and guided in their college years by him."

Earlier, in 1953, Eisenhower, in an address to the United Nations in which he solemnly appraised the grave problems facing the world in the Age of Atomic Powers, raised the possibility of an international Atomic Energy Agency. It would help steer some of the growing, menacing stockpile of fissionable material away from warlike to peaceful purposes, "to open up a new channel for peaceful discussions . . . to shake off the inertia imposed by fear . . . to make a positive progress toward peace."

These words fell on many receptive ears. To Rabi, they confirmed his growing faith in science as, inter alia, a peaceful ambassador for international cooperation. As the then-chairman of the general advisory committee of the U.S. Atomic Energy Commission (AEC), he responded to an invitation from the chairman of the AEC for proposals to translate Eisenhower's plea into some form of action.

Early in 1954, Rabi suggested an international conference on "The Peaceful Uses of Atomic Energy." At first he met (as usual) with lukewarm response from some European colleagues. But familiarity with such initial circumspection and Eisenhower's own enthusiasm led him to persist in his efforts to persuade.

By year's end, Rabi had won a broad consensus. On December 4, 1954, the General Assembly of the UN unanimously adopted a resolution to sponsor "a technical conference of governments . . . under the auspices of the United Nations, to explore the means of developing the peaceful uses of atomic energy through international cooperation." UN Secretary-General Dag Hammarskjöld formed an advisory committee of scientists in January 1955. Rabi was the U.S. representative on this committee.

The unquestionable success of the first such conference (Geneva, August 1955) vindicated Rabi's judgment and his optimism. There were 3,000 participants from 73 countries (from both sides of the Iron Curtain). There was surprisingly high praise from the Russian delegate, physicist Vladimir Veksler, who called the meeting "not only the first truly great international conference in the field of physics. . . . It has opened up splendid perspectives for the peaceful utilization of atomic energy."

There were successors to the 1955 conference-in 1958, 1964, and 1971. Its success undoubtedly enhanced Rabi's political status-and effectiveness-in the 1957 deliberations leading to the creation of the PSAC, not to mention Eisenhower's rapport with Rabi and his esteem of scientists. Witness his flattering comment of the PSAC: "This bunch of scientists was one of the few groups I encountered (in Washington) who seemed there to help the country and not themselves." He confided that some of the most invigorating times he had while president were his meetings with them.

Columbia's First University Professor

In 1964, the new title University Professor was established at Columbia and Rabi was, appropriately enough, the first to be so designated. Rabi's counsel was sought on an ever-widening range of government, academic, scientific, and industrial matters. Innumerable public honors and awards rested lightly on his shoulders. Perhaps his most cherished acclaim was one not known publicly: his nomination for the 1944 Nobel Prize for Physics was signed by Einstein and Fermi.

Science for Rabi remained a deeply personal affair. His home was in New York, and his life work, laboratory, and office were in Pupin, a stone's throw away, as it had been for more than half a century. Rabi continued to grace both the laboratory and the tea room to greet students, faculty colleagues, and friends, and to appear at the weekly colloquium. He was indomitable and seemingly timeless. Indeed, Rabi confessed that if he could choose where and how to leave this world it would be to "pass out peacefully" in a physics colloquium, adding that he hoped this would not be interpreted as criticism of the colloquium speakers or censure of its committee.

Rabi's influence was most often and most deeply appreciated in his personal interactions. His dominant characteristic was his informality, expressed by unfeigned candor, announced by a friendly smile or sometimes a not-unfriendly frown. He recognized formal structures and authorities as necessary, albeit of limited value; he tolerated and at times exploited them, but he rarely relished them. This informal atmosphere infused all Rabi's works, in teaching, research, in politics.

Rabi's teaching style was not, by formal standards, outstanding. So it was especially gratifying to him, and perhaps affirmed his faith in American institutions, when in 1981 the American Association of Physics Teachers awarded him (at the age of 83!) its Oersted Medal for distinction in teaching physics, citing "his persuasive influence on American physics, through his own work, and through the contributions of his many students."

"Wisdom is to be judged by its children." This truth is illustrated by the "Rabi Tree," a tree-chart of scores of prominent scientists Rabi influenced, published in a volume presented to him by the New York Academy of Sciences on his seventieth birthday.

Before World War II, science was a much smaller enterprise than it is today. Physics, in particular, had hardly attained the rank of a profession outside academe. In the time-compressed, breathless pace of war, however, potential leaders matured at an accelerated rate. Comparatively young scientists became, at the peak rather than the end of their careers, the new statesmen and elders of science. And American science especially had acquired its leaders, Rabi preeminent among them.

In the postwar renaissance of science, the task of the new leadership was not only to promote and develop science per se, but to guide its utilization and to guard against its misuse. "Nature," Francis Bacon had written more than three centuries earlier, "must in order to be commanded, first be obeyed." Mankind has developed vast skill in "obeying" nature. Ahead lay the much more daunting-at times terrifying-task of commanding. This would demand as much wisdom as knowledge. In Rabi's words, "Wisdom makes itself manifest in the application of knowledge to human needs. In a world that has amassed armaments sufficient to destroy if not all mankind then all fruits of human civilization many times over, survival must be ranked high among the human needs."

The tremendous experiences of World War II held many lessons. The immense power of science was driven home with a vengeance. Its primary drive may lie in the human yearning for knowledge and understanding, but its manifestations transform human labors and appetites. The exigencies of war magnified its potential-economic, technological, and social-to the point that science (cum technology?) might almost seem to be self-determining, to contain within itself the criteria for its own development. The more relaxed and contemplative postwar atmosphere permitted that the issues be examined more critically. And where else than at the university?

Some of the postwar developments-of better and bigger science-led one to circumspection. Rabi himself played a key role in the development of mega-science, involving cooperation too vast to be enveloped in an academic milieu. Science developed its own, and in its own, institutions. Rabi himself could not wholeheartedly follow. He had helped open the door into this future but did not pass through. His science was too personal, too rooted in academe to be transposed to the giant arenas of "big" science.

Rabi had collected some of his writings under the rubric "Science: The Center of Culture." Perhaps a more mellow phrase would have placed it at the center of culture-in the university, which was for Rabi a "repository of the past, a teacher and critic of the present, and through its science, an architect of the future." For Rabi science had a function in the university that transcended the "demands" of science itself. Perhaps it was here that the authentic and fundamental character of science-its essential contribution to the essential wisdom of our culture-was to be felt.

From time to time in preparing this tribute to Rabi, I have asked myself, "How would Rabi have reacted to this celebration of Columbia's 250th anniversary?" I recall that many years earlier, I was contemplating some explorations in the history of physics and happened to mention them to Rabi. His prompt reaction, albeit with some feigned expression of surprise was "What? History of Science? At Columbia, in science, we don't *study* history, we *make* it!" Making science, was, to Rabi, making history-an essential part of our cultural history. Rabi's culture was a wide and generous one that included knowledge of and respect for the past, full participation in the present, and contributions (through science) to its future. Science was at the center of his culture. And he was fond of drawing contrasts between contemporary political history and the time of the founders of the country-a time when the spirit and ideals of the republic had roots closer to those of science and reason and practices based on honest labor and experience. Franklin epitomized this character. He was Rabi's hero, "my ideal man . . . the figure in American history most worthy of emulation . . . by scientists and nonscientists alike . . . everywhere."

For both Rabi and Franklin, science represented not only a power to alleviate life's burdens but also a sort of ideal with which to inspire more mundane affairs-even to transcend them. The ubiquity of its principles, their infinite expression in detailed actuality, and the endless subtleties and surprises (the lifeblood of science for its devotees) were awe-inspiring. Not for them the hubris of achievement, but the humility of what lay beyond, unaccomplished. "Knowledge is proud that it knows so much, wisdom is humble that it knows no more."

Humility could be evoked and expressed no less by the primitive "natural philosophy" of Franklin's day than by the sophisticated physics of Rabi's. For both men, it was the counterpart of the elation elicited by a spell of intense concentration on and mastery of science's subtleties. Thus Franklin, after a couple of years of (almost) total immersion in the mysteries of electricity (1750-style), could claim: "If no other use is found for Electricity, this much is certain: it makes a vain man humble." To which Rabi would have added "Amen!"

The Reverend Samuel Johnson and his eight students in 1754, Ben Franklin with his kite on the banks of the river Schuylkill, Columbia today with its many thousands, and Rabi's Pupin with its sophisticated subtleties and exquisite instruments, are worlds apart. Yet all are embraced by the transcendental natural laws, of which humble humans can discern a glimmer-guided by Franklin's principles of truth, honesty, and integrity. And both Franklin and Rabi could-each with his own interpretation-endorse the motto chosen for Columbia by the Reverend Johnson: "*In lumine tuo videbimus lumen*" ("In Thy light shall we see light." Psalm 36:9).

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