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Physics in Perspective

The Physical Tourist

Physics and New York City

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I discuss the contributions of physicists who have lived and worked in New York City within the context of the high schools, colleges, universities, and other institutions with which they were and are associated. I close with a walking tour of major sites of interest in Manhattan.

Key words: Thomas A. Edison; Nikola Tesla; Michael I. Pupin; Hall of Fame for Great Americans; Albert Einstein; Otto Stern; Henry Goldman; J. Robert Oppenheimer; Richard P. Feynman; Julian Schwinger; Isidor I. Rabi; Bronx High School of Science; Stuyvesant High School; Townsend Harris High School; New York Academy of Sciences; Andrei Sakharov; Fordham University; Victor F. Hess; Cooper Union; Peter Cooper; City University of New York; City College; Brooklyn College; Melba Phillips; Hunter College; Rosalyn Yalow; Queens College; Lehman College; New York University; Courant Institute of Mathematical Sciences; Samuel F.B. Morse; John W. Draper; Columbia University; Polytechnic University; Manhattan Project; American Museum of Natural History; Rockefeller University; New York Public Library.

Introduction

When I was approached by the editors of *Physics in Perspective* to prepare an article on New York City for The Physical Tourist section, I was happy to do so. I have been a New Yorker all my life, except for short-term stays elsewhere on sabbatical leaves and other visits. My professional life developed in New York, and I married and raised my family in New York and its environs. Accordingly, writing such an article seemed a natural thing to do. About halfway through its preparation, however, the attack on the World Trade Center took place. From my apartment house I watched as the South Tower collapsed. Writing about New York and the role it has played in the history of physics in the United States and the world has now taken on a very different meaning.

How the relatively recent history of physics has unfolded in New York is one of the many stories that make up the marvelous mosaic that describes the city. It is therefore both with pride and a feeling of humility that I present this story now, prepared in a somewhat different form than I originally had intended. It was to

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have been a relatively straightforward tour of the many sites in New York related to physics; instead it has become what I unabashedly could call a story in praise of both my city and its physics, and how they have worked together to produce the remarkable pattern that stands unique in the world. I am aware that I cannot do justice to all of the significant events that have transpired in New York, not only because that would make this article much too long, but also because I simply am not knowledgeable enough to do it full justice. Still, I am willing to try. To maintain some semblance of brevity, I simply mention without detailed discussion some of the important New York colleges and universities that possess physics departments devoted only to service.

In trying to identify and locate specific addresses associated with particular physicists, I quickly learned one of the basic lessons about the history of New York City, namely, that it is extraordinarily ephemeral, unlike the far older and established cities of the Old World that produced so much physics in earlier times. Occasionally one comes across a plaque describing some important event that took place at some particular location, but one finds that the building with which it was associated no longer stands, having been replaced by a bigger building or an apartment complex or, like the main laboratory of Bell Telephone Labs, has been simply abandoned by the Bell Telephone Company to metamorphose into an upscale condominium for artists and similar creative people. Likewise, one of the major unsung locations in New York, used by most experimental physicists after the second world war, was the electronics center of New York where one could buy at bargain prices used and war-surplus microwave hardware, power-oscillator tubes, and the myriad electronic components that ended up as frequency sources, power generators, centimeter and millimeter-wave radiation sources, and the like. This center was located in the vicinity of Cortland Street in downtown Manhattan. It was totally eradicated to make way for the World Trade Center.

The story of physicists who emigrated from other countries is a well-told one, for example by Laura Fermi in her book, *Illustrious Immigrants*.[1] In a literal sense (though this may be stretching it a bit) the reach of New York extends to virtually *all* European émigré physicists (and everyone else for that matter), since before commercial aviation took over, New York harbor, in particular Ellis Island and Castle Clinton, were the landing points of nearly everyone coming from Europe for almost a full century.

Physics did not take hold in New York in the nineteenth century as dramatically as it did, for example, at universities such as Harvard, Princeton, Johns Hopkins, and Yale. New York's first major accomplishments were of a more practical nature, rather than of fundamental discoveries. Only later, starting between the two world wars, and accelerating with the influx of European physicists fleeing Nazi Germany, did ''real'' physics blossom in New York.

Two Famous Serbs and an American from the Midwest

Near the end of the nineteenth and beginning of the twentieth century, America was a hotbed of invention and technological innovation. For our purposes I single

out three extraordinary people, each of whom became famous for some practical developments, and all of whom were connected with New York City. These were the inventors Thomas Alva Edison (1847–1931),[2] Nikola Tesla (1857–1943),[3] and Michael Idvorsky Pupin (1858–1935),[4] all of whom were involved, in one way or another, with electrical phenomena. Edison was of Midwestern stock, while both Tesla and Pupin were Serbian, with strong roots in Serbia and Croatia, respectively. All three were self-made men, coming from either modest or, in the case of Pupin, impoverished backgrounds, and had no connections to academia or pure science. While none of these highly talented individuals could be claimed to be a "true" physicist, each made practical contributions that turned out to be of significant value to physics.

Edison's purest scientific discovery was the "Edison effect," that is, thermionic emission, although in keeping with his generally practical outlook on research he never fully understood or exploited this discovery, which was taken advantage of much better by others. While his research laboratory was famously located in Menlo Park, New Jersey, his power-generating and distribution plants were in New York, at 65 Fifth Avenue and 255–257 Pearl Street, respectively.

Tesla arrived in New York in 1884, bearing a letter of introduction to Edison, who immediately hired him. However, in later years they had a falling out, primarily because of the controversy regarding the use of alternating (ac) *versus* direct (dc) current for electric power. Tesla achieved considerable renown when he developed practical ac generators, and most impressively, three-phase generators and motors. These had a profound influence on heavy industry in New York and elsewhere. A famous struggle developed, particularly in New York, between proponents of dc electric power, notably Edison and what evolved eventually into General Electric, and ac electric power, championed by Tesla among many others, and what evolved eventually into the Westinghouse Corporation. Even today, dc-power generators exist in New York because some industrial motors, mainly in elevators in old buildings, still require dc, although Con Ed (Consolidated Edison), responsible for supplying virtually all New York power, does not itself possess dc generators any longer. Physicists are familiar with the Tesla coil, used in elementary-lecture demonstrations. Tesla possessed 700 patents.

Over time Tesla ran several laboratories in downtown Manhattan, notably first at 33–35 South Fifth Avenue (renamed La Guardia Place) and then at 8 West 40th Street, which was conveniently close to the main branch of the New York Public Library at 42nd Street and Fifth Avenue. In keeping with the long tradition in New York of tearing down old buildings and replacing them with bigger and better ones, a huge New York University apartment complex now sits at 33–35 South Fifth Avenue where the Tesla Electric Company formerly sat.

Tesla led a very colorful life in New York. For a time he was a darling of the social set, and at his peak lived luxuriously in the Waldorf-Astoria Hotel at 301 Park Avenue. Altogether he lived in seven different hotels, most of which no longer exist. There are amusing stories about some of Tesla's claims, for example, that he had developed a death ray, something like a laser but of course with no real basis in reality. Tesla made a strong mark on turn-of-the-century life in New York, but in later years he became more and more eccentric, and even mentally disturbed. His

reputation fell lower and lower. He died in 1943, in debt, in the Hotel New Yorker (corner of 34th Street and Seventh Avenue), where he had an apartment and laboratory on the top floor.

Of these three great inventors, Michael Pupin stands out as being the one with the most impressive scientific credentials, which led to his achievements in electromagnetism, radiation and electric-transmission theory, and radio research, based upon a solid background in physics. His rise from poverty and ignorance, from a tiny Serbian village in Croatia, with illiterate parents, to his final eminence as professor of electrical engineering at Columbia University, is well articulated in his autobiography, *From Immigrant to Inventor*. Pupin pulled himself up by his own bootstraps. When he first arrived in New York, in 1868, after several years working on farms in Delaware and elsewhere, he worked in factories during the day and attended lectures at Cooper Union (see below) at night. He had great ambitions, at first centered on attending Princeton University, but later changing his allegiance to Columbia. I quote from his autobiography: "[In choosing Columbia over Princeton, the] fact that the college was located in the city of New York carried much weight, because New York appealed to my imagination more than any other place in the world."[5] After receiving his undergraduate degree at Columbia College, he pursued higher education at the University of Cambridge, and finally received a Ph.D. degree from the University of Berlin. In his later years he lived in the famous Dakota apartment house on Central Park West (1 West 72nd Street). There is a statue of him (Fig. 1) at the Serbian Orthodox Cathedral of St. Sava, 12 West 25th Street. The greatest monument to Michael Pupin in New York, however, is the Columbia Physics Building, named after him, and now on the list of national historic landmarks of the U.S. Department of the Interior. He died in 1935 and is buried in Woodlawn Cemetery (Section 86, Locust Plot) in the Bronx.

The Hall of Fame for Great Americans

There are hundreds of "Halls of Fame," from baseball to country music to bronco busters, but the original one is the Colonnade (Fig. 2), part of a noble complex of buildings designed by Stanford White and founded in 1900, located on a bluff overlooking the Harlem River in the Bronx. The site was a British battery and fort during the Revolutionary War. It now houses the Bronx Community College, part of the City University of New York (CUNY), formerly the University Heights campus of New York University (NYU). It was sold to the city at the time of a devastating financial crisis experienced by NYU in 1972. The campus and the Colonnade remain intact, well-maintained by the city. The Colonnade and its abutting classic building, the Gould Memorial Library, have been designated as national historic landmarks. Its main entrance is on West 181st Street (Hall of Fame Terrace), off University Avenue, easily reached by the No. 4 subway; exit at the Burnside Avenue station. There also is parking on the campus.

At present the Hall of Fame contains 98 bronze busts of Americans of noteworthy achievement, with room for only four more, which have been preempted but are awaiting funds for commissioning. Many of the 98 busts were sculpted by distin-

Fig. 1. Bust of Michael I. Pupin (1858–1935) at the Serbian Orthodox Cathedral of St. Sava, 12 West 25th Street. Photograph by the author.

guished artists. Among those represented, in addition to Peter Cooper (1791–1883) and Benjamin Franklin (1706–1790), are seven individuals we all recognize as scientific pioneers: Alexander Graham Bell (1847–1922), No. 2; Samuel F. B. Morse (1791–1872), No. 18; Thomas Alva Edison (1847–1931), No. 21; Albert Abraham Michelson (1852–1931), the first American to receive the Nobel Prize in science, No. 23 (Fig. 3); George Westinghouse (1846-1914), No. 12; and two astronomers, Simon Newcomb (1835–1909), No. 10, and Maria Mitchell (1818–1889), No. 11. But the most impressive members of this pantheon, at least for me, are the two great American physicists Joseph Henry (1797–1878), No. 17 (Fig. 4), and Josiah Willard Gibbs (1839–1903), No. 18 (Fig. 5). It is well worth the trip just to see these two early originals, resting among the famous artists, writers, politicians, business men, and inventors of the time. Each niche carries inscriptions of significant statements made by the men and women honored. I particularly admire the one by Gibbs: "One of the principal objects of theoretical research is to find a point of view from which the subject appears in its greatest simplicity."

Fig. 2. The Colonnade of the Hall of Fame for Great Americans. Photograph by the author.

More on the history of the Hall of Fame for Great Americans can be found on its website < www.bcc.cuny.edu/HallofFame/ > . Its Director, Ralph Rourke, will be happy to talk to you about the Colonnade and other features of the site; his telephone number is 718-289-5161.

Albert Einstein, Otto Stern, and Henry Goldman

The career of Albert Einstein (1879–1955) unfolded first in Europe and then at Princeton University; his interactions with New York City therefore might seem peripheral to his principal scientific activities. Nevertheless, there are several events linking him to the city that are worth relating. The first was his arrival along with his wife Elsa on the *Rotterdam* at Ellis Island on April 2, 1921, as recorded on the ship manifest (Fig. 6). I obtained this record from the ship-manifest archive recently made available at Ellis Island, mainly through the extraordinary efforts of the Mormon Church.* Einstein came to the United States for the first time partly to help raise funds for the Hebrew University of Jerusalem, although he also gave a

* This effort was initiated by the Mormon Church for theological reasons. Readers can play a fascinating game by going to the Ellis Island website < www.ellisisland.org > and searching ship manifests for arrivals of physicists (and family members) from about 1892 to 1924.

Fig. 3. Bust of Albert A. Michelson (1852–1931). Photograph by the author.

number of lectures around the country. By this time he had become an icon for the scientific highbrow, mainly owing to Arthur Stanley Eddington's confirmation of his general theory of relativity in 1919 by measuring the deflection of starlight by the Sun during a solar eclipse. I cannot fathom why Einstein had to go through Ellis Island, since he obviously was entering the United States only as a visitor. Later that year he also picked up his Nobel Prize in Stockholm "for contributions to theoretical physics, especially the photoelectric effect." Incidentally, Einstein's first lecture in America on his first visit was at City College just a few days after his arrival, on April 7, 1921. His subject was general relativity.

There is a lovely story that links Einstein and Otto Stern (1888–1969) to the well-known New York investment house of Goldman Sachs & Co., actually to the head of the company at that time, Henry Goldman (1857–1937).* Stern received his Ph.D. degree in Breslau in 1912 and then went as a postdoctoral associate to Einstein in Prague and moved with Einstein to Zurich in 1913, where he became an unsalaried lecturer (*Privatdozent*) at the Federal Institute of Technology (*Eidgenössische Technische Hochschule*). In 1914 Stern moved to the University of Frankfurt,

* I thank Peter L. Thompson of Goldman Sachs & Co. for supplying me with copies of correspondence between Henry Goldman and Einstein as well as some detailed obituaries of Goldman. I also thank Diana Barkan, Editor of the Einstein Papers at the California Institute of Technology, for sending me some additional material, and Horst Schmidt-Böcking, University of Frankfurt, for calling this story to my attention in the first place.

Fig. 4. Bust of Joseph Henry (1797–1878). Photograph by the author.

and after serving in the German army during the war returned to Frankfurt to work in Max Born's institute for theoretical physics. He soon switched from theoretical to experimental physics, however, and in 1920–1921 with his experimentalist colleague Walther Gerlach (1889–1979) performed the remarkable experiments on spatial quantization that became of crucial importance for the emerging quantum mechanics. Born (1882–1970), however, had had difficulty in finding funds for Stern's experiments, but through some personal connections was told to write to Henry Goldman, 998 Fifth Avenue, New York. Soon "a most charming reply arrived and a cheque for some hundreds of dollars which helped us out of all our difficulties."[6]

In 1921 Born left Frankfurt for Göttingen, and Stern left Frankfurt first for Rostock and then, in 1923, for the University of Hamburg to organize a laboratory specifically devoted to molecular-beam research, where a few years later the young I.I. Rabi learned the tools of this trade. Henry Goldman, in addition to being an important financier in New York, was a noted philanthropist, art collector, and leader in the New York Jewish community. Born recalled that, "Goldman was a great help indeed. He continued to assist our research by giving money, and he did the same with many other German scholars. I brought him into contact with Einstein, and a few years later they both visited us [my wife and me] in Göttingen and stayed in our house."[7] In 1933, after Hitler came to power, Born was forced to leave Göttingen and Stern Hamburg. Einstein then turned to Goldman for help

Fig. 5. Bust of Josiah Willard Gibbs (1839–1903). The caption reads: "One of the principal objects of theoretical research is to find the point of view from which the subject appears in its greatest simplicity." Photograph by the author.

both in rescuing individual German Jews and in raising the consciousness of America to the persecution of Jews in Germany.

Oppenheimer, Feynman, Schwinger, and Rabi

Four of the most famous physicists of the twentieth century were born and grew up in New York City. Three were theoretical physicists, but their styles, personalities, and characters were totally different. J. Robert Oppenheimer (1904–1967) was aesthetic and shy,[8] Richard P. Feynman (1918–1988) boisterous and exuberant,[9] and Julian Schwinger (1918–1994) gentle and good-natured for the most part.[10] Oppenheimer came from a privileged, highly cultured, assimilated family of German Jews, Feynman from a more typical immigrant family of Russian Jewish

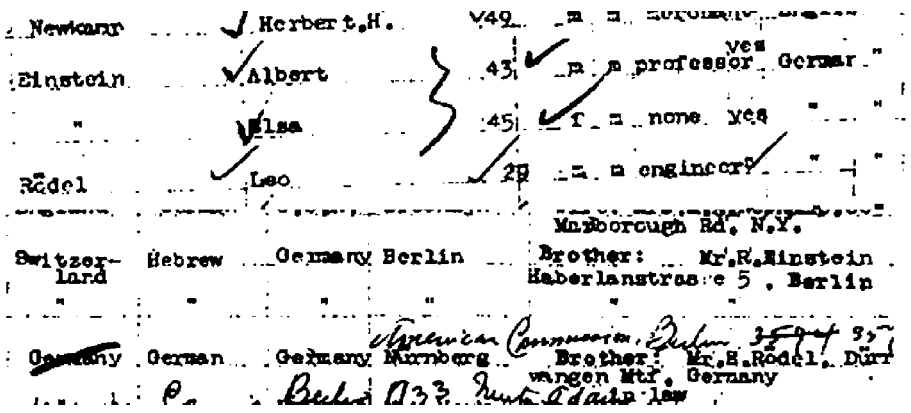

Fig. 6. Passenger manifest of the *Rotterdam*, April 2, 1921, showing the names of Albert and Elsa Einstein. Document preserved at Ellis Island.

background, and from what one might now call lower-middle class, and Schwinger from a comfortable, middle-class Jewish family. Oppenheimer went to the Ethical Culture School (35 Central Park West) through high school, a very refined school that espoused an abstract kind of "religion" – actually philosophy – that appealed to non-practicing, liberal Jewish families. Feynman went to a regular city public school, PS 39 (corner of State Street and Roanoke Avenue, since relocated) in Far Rockaway, and then to Far Rockaway High School. Schwinger went to a regular public school in Manhattan and then to Townsend Harris High School (see below). Oppenheimer grew up in a fine, art-filled Riverside Drive apartment (155 Riverside Drive, off 88th Street), with a view of the Hudson River. Feynman grew up in a modest but comfortable two-family house (14 New Broadway in Far Rockaway) in one of New York City's most remote (and attractive) neighborhoods adjoining the Atlantic Ocean – a fine place for anyone to grow up, even without family money. Schwinger's background was what one could call normal, a family with love and high ambition for their children, growing up, as did Oppenheimer, also on Riverside Drive, but in its more middle-class neighborhoods, first a mile or two north of Columbia University on 140th Street and later on 103rd Street, close to Columbia. They all had one quality in common – they were brilliant as children, prodigies in fact, and stood out in high school and even more so in college. Their early promise got them into Princeton (Feynman), Harvard (Oppenheimer), and Columbia (Schwinger). Oppenheimer went on to acquire fame as Director of Los Alamos when it was developing the atomic bomb during World War II. Feynman went on to acquire fame at a very young age as the most brilliant theoretical physicist at that laboratory. Schwinger (who just before the war actually worked two years with Oppenheimer in Berkeley) achieved fame among physicists while at Harvard, although he never became a public icon as did the other two – he was a physicist's physicist.

The story of how Schwinger ended up at Columbia as an undergraduate is a New York legend that involves all three major New York colleges. Schwinger started at

City College, because he was unable to obtain a full scholarship elsewhere, despite his obvious brilliance. In his first two years he attracted the attention of some of the most perceptive physics faculty there. Lawrence A. Wills (b. 1908), who taught him in a quantum-mechanics class, steered him to a weekly seminar organized by Otto Halpern (1899–1982) at NYU in the Bronx, which was a lively meeting place for NYU, CCNY and Columbia physicists, including Gregory Breit (1899–1981) of NYU and Rabi of Columbia. In fact, Schwinger (at age 17!) and Halpern published a paper in *The Physical Review* on multiple scattering involving polarized electrons.[11] Apparently, however, it was Lloyd Motz (b. 1910) of Columbia who called Schwinger to the attention of Rabi, who arranged a full scholarship for him at Columbia for the remainder of his undergraduate studies – and the rest, as they say, is history.*

Of the four New Yorkers who achieved everlasting fame in physics and society, the only one to spend his entire career in New York was Isidor I. Rabi (1898–1988). Rabi was born into a poor Jewish family in Rymanow, a small town in Galicia in the northeastern Austro-Hungarian Empire, and was brought to New York as an infant by his parents. He graduated from the Manual Training High School (237 7th Avenue, now the John Jay High School) in Brooklyn in 1916 and then entered Cornell University, obtaining a bachelor's degree in chemistry three years later. After graduation he worked for three years before returning to Cornell for graduate study in physics, but spent only one year there before transferring to Columbia, where he received his Ph.D. degree in 1927. He then spent two years as a postdoctoral fellow in Europe, especially with Wolfgang Pauli (1900–1958) and Otto Stern in Hamburg, where he began the molecular-beam experiments that would be decisive for his future research. He returned to Columbia in 1929 as a lecturer in physics. In 1931 he and Breit developed the famous Breit-Rabi formula, the lodestone that opened up the entire field of resonance physics.[12] In subsequent years, Rabi built up at Columbia one of the most influential schools of research in America, aptly illustrated by the famous Rabi Tree showing Rabi at the base of a broad trunk that is filled with him and his collaborators and students and that sprouts numerous branches displaying the influence of his work on many others.[13] During all of his years at Columbia, he and his wife Helen (and their two daughters when they were young) lived in a nearby apartment house at 450 Riverside Drive, corner of 116th Street.

Of these four famous New York physicists, three were awarded Nobel Prizes, Rabi in 1944 and Feynman and Schwinger in 1965.

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* I thank my officemate at NYU, Sidney Borowitz, for describing to me details concerning Schwinger's stay at City College. Borowitz knew Schwinger very well, having attended a number of physics and mathematics classes with him. According to Borowitz, Schwinger was the scourge of many of his teachers. He rarely if ever did his homework, and generally approached problems from the very beginning, working his way through everything needed to complete the work. Most of his teachers simply couldn't deal with this. Borowitz eventually became one of Schwinger's postdoctoral students at Harvard.

New York City High Schools

New York City high schools have been a breeding ground for physicists for at least three quarters of a century. While it is tempting to simply catalog the unusually large number of Nobel Prize winners who went to New York high schools, there are a vastly greater number of physicists who have had distinguished careers, with assorted accompanying honors, who attended these schools, almost all of them within the free public school system. Many of these physicists were children of immigrants, or immigrants themselves, some coming from families living in poverty, at the lowest rungs of the economic ladder.

Regarding Nobel Prize winners, however, Bronx High School of Science (website < www.bxscience.edu >), now at 75 West 205th Street in the Bronx, is the leader, far and away, in their production. No fewer than five Nobel Laureates have come from this single high school: Leon N. Cooper, class of '47, Melvin Schwartz, '49, Sheldon L. Glashow, '50, Steven Weinberg, '50, and Russell A. Hulse, '66. The Bronx High School of Science is one of three city high schools that are particularly oriented to science, and to which admission is determined by competitive examinations throughout the city, the other two being Stuyvesant at 345 Chambers Street in Manhattan (website < www.stuy.edu >) directly opposite the site of the World Trade Center, and Brooklyn Technical High School at 29 Fort Greene Place (< website www.bths.edu >) in Brooklyn.* Stuyvesant can claim as alumni Roald Hoffman,** Nobel Laureate in 1955 (all right – he was a physical chemist and also later a graduate of CCNY), as well as Brian Greene, Steven Koonin, Hans Mark, Paul C. Martin, Marshal Rosenbluth, and Nick Samios. Brooklyn Tech can claim Arno Penzias, Nobel Laureate in 1951. Leon Lederman, Nobel Laureate in 1988, went to James Monroe High School in the Bronx. Rosalyn Yalow, Nobel Laureate in 1977, went to Walton High, an all-girls school also in the Bronx, at the time a virtual "prep school" for Hunter College, to use a term more appropriate for prestigious private schools. Probably the most surprising source of a top-rank physicist was the Manual Training High School (now John Jay High School), which as noted above was attended by I.I. Rabi. Also worthy of mention is Columbia Grammar, where Murray Gell-Mann, Nobel Laureate in 1969, wowed them all.[14] And, of course, Far Rockaway High, where Richard Feynman spent four years. To add further glitter to that school, so did Burton Richter, Nobel Laureate in 1976.

In a conversation with Olga Livanis, Chair of the Department of Chemistry and Physics at Stuyvesant, she reminded me that her school houses students of every economic stratum, from very rich to impoverished, and that many of its students are immigrants, in either the first, second, or third generations, from over

* The battle in New York City to protect these three special schools from the near-fatal charge of elitism eventually led, after bitter political battles, to the Hecht-Calandra bill in 1971, which mandated that admission to these three schools be decided exclusively on the basis of entrance examinations, later modified somewhat to encourage minority students to apply.

** I strongly recommend reading his autobiography on the Nobel Prize website < www.nobel.se > .

100 countries. This pattern is followed in all of the special science schools of New York, since their populations come from the entire city, and accordingly represent a microcosm of the city itself, if somewhat biased towards ability and talent in the sciences.

A fourth high school, Townsend Harris (website < www.thhs.gc.edu >) at 149-11 Melbourne Avenue in Queens, regarded as a "prep school" for CCNY, was considered to be the elite of the elite. But in one of the many financial crises that New York experiences from time to time, the beloved Mayor Fiorello La Guardia abolished it in 1942.* William Nierenberg (1919–2000), late Director of the Marine Biological Institute in La Jolla, California, is a Townsend Harris graduate and also a graduate of CCNY. So is Herbert Hauptman, Nobel Laureate in Chemistry in 1985 for his work in developing techniques for computing crystal structure. And, as noted above, Julian Schwinger attended City College, but graduated from Columbia. A half century after it was abolished, a group of alumni somehow managed to resuscitate Townsend Harris, this time in Queens, with an affiliation with Queens College. It is now as dynamic as it was in its first incarnation. Among other things it is noted for the oath that is administered to new students, called the Ephebic Oath, from a similar oath taken by students in ancient Greece. In the conclusion of my article I cite this oath, which in my opinion reflects the close connection students have with their city.

As is characteristic of New York, most of these high schools no longer occupy the buildings they did in their earlier days, but have moved on to bigger and better ones.

The New York Academy of Sciences

The New York Academy of Sciences (NYAS) at 2 East 63rd Street (Fig. 7) was founded as the Lyceum of Natural History in the City of New York in 1817 and published its first *Annals* in 1823. In 1831 members of the Lyceum played a major role in founding New York University, and in 1869 they helped to found the Museum of Natural History. In 1876 the Lyceum changed its name to the New York Academy of Sciences. The physics section of the NYAS holds periodic meetings and sponsors its share of conferences and symposia, but perhaps the most important role that the NYAS has played, with physicists at the fore, has been its leadership in human rights. It has taken up the cause of scientists who have been persecuted by their governments over the years; the cases presently before it are described on its website (< www.nyas.org >). The most noteworthy of all of its human-rights' cases – one that played a significant role in loosening the tight grip of communism on the U.S.S.R. – was that of Andrei Sakharov (1921–1989).

* In a famous La Guardia quote, referring to this decision, he stated in effect, "I don't often make mistakes, but when I do it's a beaut." There is a new and extremely informative book by Eileen L. Lebow (ref. 15) about the unsuccessful struggle to preserve Townsend Harris against its would-be eliminators. This book also discusses in some detail aspects of the history of CCNY, including the sad era of communist witch hunts that appeared in New York well before the McCarthy era.

Fig. 7. The entryway of The New York Academy of Sciences, 2 East 63rd Street. Photograph courtesy of the NYAS.

Sakharov made his first appearance at the NYAS in 1988, and credited the NYAS with coordinating the international movement that led to his release from exile in Gorki in 1986. The NYAS pursued Sakharov's case with extraordinary vigor, essentially facing down the government of the U.S.S.R., and helped to make it a *cause celebre* around the world. For years the NYAS produced a splendid monthly magazine, *The Sciences*, replete with excellent articles and accompanying art. Unfortunately, the NYAS announced recently that it is giving up its publication, a victim of declining revenue and increasing expenses.

The NYAS has been extremely active in organizing education initiatives. It works with middle-school science educators, conducts programs to improve the New York region's science education, conducts science fairs, and helps coordinate student internships at local universities. Perhaps not coincidentally, three of its most recent executive directors, Sidney Borowitz, Heinz R. Pagels, and Rodney W. Nichols, were physicists.

Universities and Colleges

New York City has no fewer than 108 institutions of higher learning, from junior (two-year) colleges up to full-fledged universities. Of all of these I have selected to describe just those with major physics departments; there are many more with physics curricula, including Manhattan College (in the Bronx!), St. John's University, and the College of Staten Island (part of CUNY). You can access most of them through the website < www.greatcollegetown.com > .

Fordham University, Victor F. Hess, and the Washington Heights Subway

The Fordham University Physics Department is located on the beautiful Rose Hill campus at 441 East Fordham Road in the Bronx. It is affiliated with the Catholic Church, through the Jesuits. In earlier days it offered a complete advanced-degree curriculum, but in recent years its offerings have been curtailed somewhat. Some of its earlier faculty members included Joseph Budnick, now at the University of Connecticut, Alfons Weber, now at the National Institute of Standards and Technology (NIST), and Paul C.W. Chu, now at the University of Houston, who obtained his M.S. degree at Fordham. Probably, however, the best-known former Fordham faculty member is Victor F. Hess (1883–1964). The Austrian-born Hess was a pioneer in cosmic-ray research. He received the Nobel Prize in 1936 for demonstrating, through dangerous balloon ascents, that high-energy radiation in the Earth's atmosphere originated in outer space. He emigrated to the United States after the Nazi *Anschluss* of Austria in 1938 and remained on the Fordham faculty until 1956, continuing his cosmic-ray research and organizing a very active research group in this field.

To my knowledge, Hess is unique in that he enlisted the cooperation of the New York subway system in his research. The deepest subway tunnel in New York belongs to what was formerly called the IRT (Interboro Rapid Transit) and is now the No. 1 and No. 9 trains, which run along St. Nicholas Avenue in Harlem before heading for the Bronx. This is because the northern reaches of Manhattan is a very high hill, composed mostly of the famous, solid Manhattan mica schist.* The 191th Street station is 180 feet below street level, accessible to riders by huge elevators. It was an ideal spot to study the effect of radiation from rocks on cosmic rays. I reproduce the relevant correspondence in Fig. 8.

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* This is the bedrock that has made it feasible to construct skyscrapers in midtown and downtown Manhattan. It also helps explain why Greenwich Village has kept its charming, village-like character, because the bedrock sinks so low in that neighborhood that construction of tall buildings is much more difficult. For a completely overwhelming description of New York geology, see the marvellous *Encyclopedia of New York City* (ref. 28), which, incidentally, lists Rabi but not Feynman.

Cooper Union

In a city filled with unique institutions, one still stands out. Its full name is Cooper Union for the Advancement of Science and Art; it was created in 1859 and subsequently nurtured by one person, Peter Cooper (1791–1883). Cooper Union (website < www.cooper.edu >) is located at Cooper Square, close to the Lexington Avenue station of the No. 6 subway train. What makes it unique is that it was, and remains, a completely tuition-free college. It includes a physics department in one of its three schools, the Albert Nerkin School of Engineering. As noted above, one of its students, from 1966–1970, was Russell A. Hulse (b. 1950), who became a graduate student of Joseph H. Taylor, Jr. (b. 1941) at the University of Massachusetts at Amherst, where they began their joint research that led to their discovery of gravitational radiation from binary pulsars for which they shared the Nobel Prize in 1993.

May 20, 1947.

The Board of Transportation
City of New York
250 Hudson Street
New York, N.Y.

Gentlemen :

I am looking for an opportunity to carry out experiments on the radiation emitted from rocks at a location well protected from cosmic rays.

After consultation with the Department of Terrestrial Magnetism and the Geophysical Laboratory of the Carnegie Institution of Washington, D.C. it was agreed that such an experiment would require carrying out observations at a place at least 150 feet underground.

Since there are no caves in the vicinity of New York and since the instruments are at present set up at Fordham University it was suggested that the Subway System of New York may offer a suitable location for this crucial experiment.

The deepest station of the I.R.T Line is located at 191st Street and St.Nicholas Ave . I inspected this station recently and think that it would be rather easy to set up my apparatus there , without interference with the operation of the Subway and without being disturbed by the public.

The apparatus consists of an ionization meter (cylindrical ionization chamber of about 5 litres , filled with nitrogen, connected to a Lindemann electrometer and panel board with dry cell batteries) which is placed within an iron shield or housing 30" x 30" x 80", The walls of this shield are 4" thick . This " iron house" is set up on a wooden base 18" from the ground . The housing itself consists of steel plates (bottom and top) and steel bars (side wall) , weighing about 2000 lbs. The complete setup takes not more than 10 sq.ft. height about 4 ft , with a stool for the observer and a small lamp. The apparatus is, of course, completely harmless and will not produce any fumes or explosion .

The space between the ionization meter and the housing is to be filled with crushed granite (about 300 lbs) from bags.

The observations could be carried out in a side corridor of the deepest part of the station where the public has no access and where the apparatus could be left undisturbed over night.

An observer would work ever day for several hours and would have to continue for about one month.

Fig. 8.

- 2 -

The whole equipment consisting of 25 wooden blocks 7" x 4" x 4" steel plates and bars (3000 lbs) weighing about 20 lb a piece bags of crushed granite etc. would be brought to the station by truck and could be taken down on one of the elevators in one trip and set up ,together with the apparatus itself within 2-3 hours. Local help would be paid liberally by myself from a grant given to me for these experiments by the Amer. Philosophical Society in Philadelphia .

The purpose of the experiment itself is described in a memorandum attached to this letter.

May I ask you, Gentlemen, to give me permission to use the 191st Str.- St.Nicholas Ave Subway Station for these observations?

I am a professor of physics at Fordham University and have been engaged in the study of cosmic rays and allied subjects for many years . I was awarded the Nobel Prize in Physics for the discovery of cosmic rays by the Royal Swedish Academy of Science in 1936.

I shall be glad to give further information about my experiment and its requirements personally, if necessary.

July, August and September would be the best time for carrying out the experiments.

If the Board of Transportation is in favor of allowing me to begin the experiments in the named subway station it would be best if a member of your Engineering Department would inspect the station together with me to talk over the details.

Very truly yours,

Victor F.Hess.

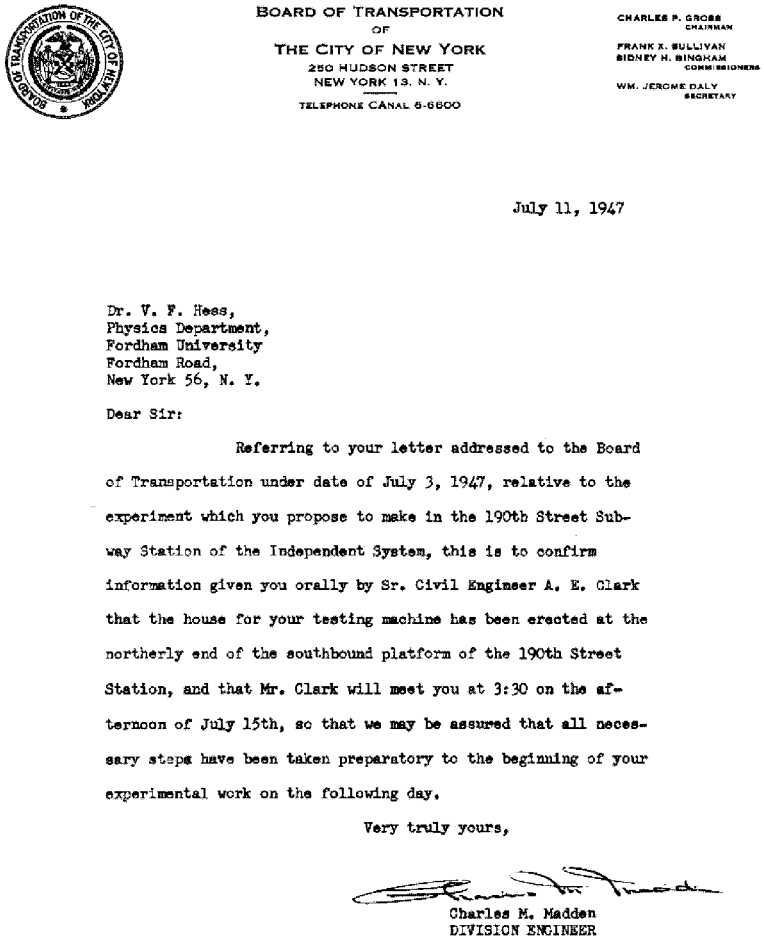
Fig. 8. (Continued).

Peter Cooper was a self-made, uneducated workingman's son who became a famous inventor and industrialist. The main building of Cooper Union is a noble brownstone pile (Fig. 9), a historic monument containing the Great Hall, famous for a pre-election speech made there by Abraham Lincoln. Thomas Edison describes in his autobiography how he took courses at night at Cooper Union – his only formal education. Cooper Union remains an active fixture in New York cultural life, with concerts and lectures galore; it is well worth a visit.

Cooper Union's students are selected competitively; it is supported by its endowment and some fortuitous real-estate holdings, greatly enhanced now by alumni contributions. In the list of the "best 331 colleges" in America, as rated by the *Princeton Review* in 2002, Cooper Union is ranked as the "hardest school to get into," followed by Harvard and Princeton!

City University of New York

The City University of New York (CUNY) is the umbrella organization that administers all of the public city colleges in New York, including City College (CCNY), Brooklyn, Queens, Hunter, and Lehman Colleges, among a number of



BOARD OF TRANSPORTATION
OF
THE CITY OF NEW YORK
250 HUDSON STREET
NEW YORK 13, N. Y.
TELEPHONE CANAL 6-6600

CHARLES P. GROSS, CHAIRMAN
FRANK X. SULLIVAN
SIDNEY H. BINGHAM
COMMISSIONERS
WM. JEROME DALY
SECRETARY

July 11, 1947

Dr. V. F. Hess,
Physics Department,
Fordham University
Fordham Road,
New York 56, N. Y.

Dear Sir:

Referring to your letter addressed to the Board of Transportation under date of July 3, 1947, relative to the experiment which you propose to make in the 190th Street Subway Station of the Independent System, this is to confirm information given you orally by Sr. Civil Engineer A. E. Clark that the house for your testing machine has been erected at the northerly end of the southbound platform of the 190th Street Station, and that Mr. Clark will meet you at 3:30 on the afternoon of July 15th, so that we may be assured that all necessary steps have been taken preparatory to the beginning of your experimental work on the following day.

Very truly yours,

Charles M. Madden
DIVISION ENGINEER

Fig. 8. Victor F. Hess's letter of May 20, 1947, to the New York City Board of Transportation, and the Board's reply of July 11, 1947. Reproduced by permission of the Hess Archive at Fordham University.

others. Each runs its own undergraduate physics program, but there is only one graduate school, which is officially housed at the CUNY Graduate Center located in its new quarters at 365 Fifth Avenue. The graduate faculty and students, however, are distributed throughout the college system, although some classes are given at the Graduate Center. Thus, the real activities of the physics program of CUNY are located at the colleges, primarily at the major senior colleges, CCNY (established 1847), Hunter (established 1870),* Brooklyn (established 1930), and Queens (established 1937).

* Hunter originally had two campuses. The one in the Bronx eventually split off to become Lehman College.

Fig. 9. Cooper Union for the Advancement of Science and Art. A plaque that was placed on the building in 1950 by The New York Community Trust notes that the building is one of the Landmarks of New York and reads: "Peter Cooper, inventor, civic leader, philanthropist, founded this institution offering free education to all. In its Great Hall, birthplace of many important social and political movements, America's leading citizens have spoken, among them Abraham Lincoln whose 1860 address here contributed to his presidential nomination. Designed by Frederick A. Peterson. This building was opened in 1859." Photograph by the author.

City College

The jewel in the crown of the physics establishment of the City University of New York is City College at 138th Street and Convent Avenue in upper Manhattan. The history of City College is an inspiring story, which is told on its website <www.ccny.cuny.edu>. Eileen L. Lebow also provides a full discussion of its establishment, early history, and more recent struggles in her book, *The Bright Boys*.[15] The American diplomat Townsend Harris (1804–1878) was instrumental in founding it as the Free Academy in 1847, with a defined mission "to educate the whole people." If you visit the campus you will note the Oxbridge inspiration of the architecture of the Main Building, now called Shepard Hall (Fig. 10). This was no accident, since the intent of the founders was to inspire a spirit of tradition in the newly minted students, mostly children or grandchildren of immigrants. The building also is a monument to the bedrock of Manhattan, since it is built out of the mica schist that had to be removed for its construction.

Prior to World War II, City College turned out generations of physicists and other scientists who later populated many of our most prestigious institutions of higher learning, government, and industry. In recent years, as part of CUNY, it has developed a graduate program with research physicists staffing it that can hold its

Fig. 10. The original Main Building of City College, now called Shepard Hall. Photograph by the author.

own against most of the better-supported universities of the country.* In its glorious pre-war years, its reputation rested particularly on two factors. First and foremost were its students. City College students (male only until the 1940s), almost all from the city's poorer population, were very talented and came from striving families having high ambitions for their children, and the children themselves were aware that the best way to escape working-class constraints was through the professions. Second, there was a small but select faculty who worked with these students to turn them into physicists. Among its members were Mark Zemansky (1900–1981), Lawrence A. Wills (b. 1908), Henry Semat (1900–1973), and for a time Clarence Zener (1905–1993), Walter Zinn (1906–2000), and I.I. Rabi.

Out of this mix emerged the generations of physicists who have become virtually legendary in their numbers and accomplishments.** The list of CCNY physics alumni includes Joseph Birman, Bernard Feld, Herman Feshbach, Morton Hamermesh, William Havens, Ernest Henley, Robert Herman, Robert Hofstadter, Leon Lederman, Harry Lustig, Sidney Milman, Arno Penzias, Frank Press, Henry Semat, Mark Zemansky, Brian Schwartz, and the author. Many of these, including the three Nobel Prize winners (Hofstadter in 1961, Penzias in 1978, Lederman in

* Two of its faculty members and two of its alumni have played major roles in the American Physical Society, the faculty members being Harry Lustig, for years Treasurer of APS, and Myriam Sarachik, President of APS in 2002, and the alumni being William Havens, Secretary of APS for many years, and the author, Editor-in Chief for five years.

** I cannot help bragging that Colin Powell – definitely not a physicist – is also a CCNY alumnus.

1988), are recipients of the City College Townsend Harris Award, given annually to a few outstanding alumni. Probably City's most famous attendee was Julian Schwinger, who however, as already noted, graduated from Columbia!

In the post-war period, City College's physics department reached its peak during the tenure of the famous physicist Robert Marshak (1916–1992) as President of CCNY (1970–1979). The relatively new science building that houses the physics department is named after him (Fig. 11).* Today, despite seemingly perpetual budgetary and other constraints, the physics department remains extraordinarily vital and productive.

Fig. 11. The Marshak Hall of Science of City College. Photograph by the author.

* The science building replaced one of New York's oldest and most beloved venues for classical music, Lewisohn Stadium. This was an open amphitheater that offered concerts in the summer by the New York Philharmonic with world-class soloists. The amphitheater seats were made of cast cement, and admission cost 25 cents. You could buy a soft pad for an additional small fee. There were more expensive seats close to the stage, but I personally never sat in them. While perhaps not directly related to physics, I can personally vouch that many budding intellectuals in the city attended these concerts regularly and were inspired by them to achieve high goals. They were frequently introduced by the greatly admired philanthropist Minnie Guggenheim, who offered pithy and humorous comments on the programs. Fiorello La Guardia also showed up from time to time. Apart from eventually outliving its usefulness, the fatal blow to Lewisohn Stadium was that it lay directly in the path of planes landing at what is now called La Guardia Airport.

Brooklyn College

After CCNY, Brooklyn College has the most active of the CUNY physics departments. Its office is at 3438 Ingersoll Hall, 2900 Bedford Avenue, in Brooklyn. A short history of the college can be found on its website <www.brooklyn.cuny.edu>. Brooklyn College has an ambitious undergraduate physics program, with an enormous number of alumni. The current chair of the department is Carl Shaken, a distinguished particle theorist. Brooklyn College also was the home of Melba Phillips (b. 1907), the first recipient in 1982 of the eponymous Melba Newell Phillips Award of the American Association of Physics Teachers. She is the co-discoverer of the Oppenheimer-Phillips effect describing the breakup of a deuteron under neutron bombardment,[16] and she is co-author with W.K.H. Panofsky (b. 1919) of the well-known textbook on classical electricity and magnetism.[17] She was one of the many victims of the McCarthy era, when she was dismissed from Brooklyn College in 1952 for her unwillingness to cooperate with the U.S. House Un-American Activities Committee. Years later, in 1987, Brooklyn College publicly apologized for this act. (Other New York colleges also suffered from that committee and from an earlier New York State committee, the Rapp-Coudert Committee, but that story, as fascinating and disturbing at it is, is outside the scope of this article.)

A not-so-random check of the list of the physicists who graduated from Brooklyn College reveals the following names: Stanley Bashkin, Joseph Sucher, Esther Conwell, Stanley Deser, Sherman Frankel, Abraham Klein, Joel Lebowitz, and both Grace and Larry Spruch.

Hunter College

Hunter College (website <www.hunter.cuny.edu>) at 695 Park Avenue maintains a small but active physics department, with research in quantum optics and laser physics, condensed-matter physics, nuclear and particle physics, and plasma physics. Hunter also is of considerable historical interest, because a fairly large number of physicists who later became famous taught there (when it was at an earlier location) to support themselves while they were either in graduate school or in junior research positions at Columbia. Jerrold Zacharias (1905–1986), for example, taught there. Rosalyn Yalow (b. 1921), however, is probably Hunter's most famous physics alumna. She was a physics major at Hunter and in 1977 received the Nobel Prize in Physiology or Medicine for her research in, and clinical use of, radioisotopes in medicine. She recalled in her Nobel autobiography that, "My mother…came to America from Germany at the age of four. My father... was born on the Lower East Side of New York, the Melting Pot for Eastern European immigrants. Neither had the advantage of a high school education...."[18] All the more remarkably, her entire scientific career – without benefit of a postdoctoral position or advanced training anywhere – unfolded at the Bronx Veteran's Administration hospital, off Kingsbridge Road in the northwest Bronx.

Queens and Lehman Colleges

Both Queens and Lehman Colleges maintain small but active physics departments. Queens is located at 65–30 Kissena Boulevard in Queens; its website is < www.qc.edu > . Lehman is located at 250 Bedford Park Boulevard West in the Bronx; its website is < www.lehman.cuny.edu > .

New York University

New York University (NYU), originally called the University of the City of New York, was founded in 1831 by a number of wealthy and influential New Yorkers who believed that their city should have an institution of higher education that would be accessible to children of middle-class and even working-class parents – students who generally were not able to attend such prestigious institutions as Columbia, Yale, Princeton, and Harvard.* Its location was and remains today at Washington Square, originally in a neo-classical building, since demolished. Especially noteworthy is that from its beginning NYU (website < www.nyu.edu >) was defined as a university, rather than a college. Accordingly, it began granting advanced degrees far earlier than Columbia, which at the time was only a college. Around the turn of the century, NYU acquired a second campus, including its classical library and colonnade (see above), on a beautiful piece of property in the Bronx called University Heights. After the second world war, as a consequence of the emigration from Germany in the 1930s of the noted mathematician Richard Courant (1888–1972) and some of his equally distinguished colleagues, a famous center of pure and applied mathematics was established at Washington Square (251 Mercer Street), now called the Courant Institute of Mathematical Science (website < www.cims.nyu.edu >).[19] The upshot was that for a long time NYU effectively had three physics departments.

In the early part of the nineteenth century, NYU had two stellar professors on its faculty, Samuel Finley Breese Morse (1791–1872) and John William Draper (1811–1882),[20] both of whom had a profound influence on technology and science. Morse was appointed to the faculty when NYU was created, with the title Chair of Sculpture and Painting. He in fact was a talented artist who produced a number of well-known paintings, including a famous one of the Marquis de Lafayette (1757–1834). He was interested in science as a hobby, particularly electrical phenomena, and in his later years gave up painting entirely to devote himself to science. Inspired by a series of lectures on electromagnetism at Columbia in 1829, he invented the telegraph and demonstrated it for the first time in the Main Building on Washington Square East, since replaced, where he also had an apartment (for which he had to pay rent; his salary at first was derived mostly from student fees). A bust of him

* I can't resist quoting from the University's Charter: "All undergraduate students are required to attend Daily Morning Prayers. The Scriptures are read followed by singing and prayer and occasionally a brief address." The founding fathers believed it was best to emulate the more fortunate students in the Ivy League colleges.

resides in the Hall of Fame for Great Americans and in Central Park, at Fifth Avenue and 72nd Street, on the south side of the drive, called the "inventor's gate."

A little later John William Draper was appointed Professor of Chemistry and Natural History, that is, of Physics. Draper was the first American to undertake a serious study of photography, following the lead of Louis Daguerre (1787–1851) in France. He also was the first American to employ photography in scientific studies, including the taking of spectrographs and, for the first time, photographs of the moon. Apparently Morse got Draper interested in photography. Together they opened a photography gallery on the top of the Main Building. Morse also opened the first commercial photographic studio in the United States at 153 Nassau Street. A plaque commemorating Draper's work is on the northeast corner of the present NYU Main Building.

Physics at NYU had its heyday in the years between the two world wars, particularly at its University Heights campus in the Bronx. Gregory Breit served as chair of the department for a time; Rabi came to attend the seminars organized by Otto Halpern, as did Schwinger when he was an undergraduate at City College. Breit and Rabi developed the Breit-Rabi formula (see above). Neutron, nuclear-structure and polarized-electron studies were pursued by Allan C.G. Mitchell (1902–1963),* Frank E. Myers (1906–1995), Otto Halpern (1899–1982), Theodore (Ted) Holstein (1915–1985), Richard T. Cox (1898–1991),** Serge A. Korff (1906–1989), Morton Hamermesh (b. 1915), John A. Simpson (1916–2000), and Fritz Reiche (1883–1969).*** Reiche lost his position in Germany and arrived in New York without a job in 1941. His first teaching position was at the New School for Social Research (now the New School University), which was created specifically to give employment to distinguished refugee scholars in the social sciences. He then taught for a short time at City College and finally received an adjunct, non-tenured

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* There always were strong interconnections between New York physics departments. For example, Mitchell at NYU collaborated with Mark Zemansky at City College on their book on atomic physics, while Zemansky, the most distinguished teacher at City College, performed his research at Columbia. We also saw how Schwinger moved from City College to NYU to Columbia.

** In 1928 Cox and his colleagues observed that electrons were polarized in beta decay, almost three decades before the experiments of C.S. Wu and her colleagues, though his work was largely neglected because, lacking any ideas concerning non-conservation of parity, his measurements were not believed. See R.T. Cox, C.G. Mcllwraith, and B. Kurrelmeyer, "Apparent Evidence of Polarization in a Beam of β-Rays," *Proceedings of the National Academy of Sciences* **14** (1928), 544–549 and C.S. Wu, E. Ambler, R.W. Hayward, D.D. Hoppes, and R.P. Hudson, "Experimental Test of Parity Nonconservation in Beta Decay," *Phys. Rev.* **105** (1957), 1413–1415. For a full discussion, see Allan Franklin, *The Neglect of Experiment* (Cambridge: Cambridge University Press, 1986), pp. 7–72.

*** Thomas Powers relates how Reiche arrived in New York as a refugee in the spring of 1941 and carried a message with him to alert American physicists to the German bomb effort, although apparently to little avail. Reiche was a distinguished physicist who worked in statistical mechanics and the early quantum mechanics and for a variety of reasons did not leave Berlin until almost the very last minute. On arriving in New York, he was greeted by Mark Zemansky. He passed his message about the German atomic bomb effort on to physicists at Princeton, but his information somehow got sidetracked, according to Powers, and never resulted in significant action by the United States. See Powers, *Heisenberg's War: The Secret History of the German Bomb* (New York: Alfred A. Knopf, 1993), pp. 103–109.

position at the University Heights campus of NYU, where I took a memorable course in statistical mechanics from him. His family recently deposited his papers – ten full boxes – in the Niels Bohr Library of the American Institute of Physics Center for History of Physics in College Park, Maryland; they are fascinating to read.

Two Nobel Prize winners did their graduate work at University Heights: Clifford G. Shull (1915–2001) who received the Nobel Prize in 1994 "for the development of the neutron diffraction technique," and Frederick Reines (1883–1998) who received the Nobel Prize in 1995 "for the detection of the neutrino."

After the University Heights campus was sold to New York State, physics at NYU became concentrated at the Washington Square campus, mainly at the Meyer Hall of Physics at 4 Washington Place (Fig. 12). After the second world war, NYU developed important laboratories in atomic physics (Werner Brandt, Henry Stroke, and myself); it became an equally important center for atomic collision theory

Fig. 12. The Andre and Bella Meyer Hall of Physics of New York University. Photograph by the author.

(Larry Spruch, Leonard Rosenberg); and it also housed a famous laboratory led by Hartmut Kallmann (1896–1978), yet another German refugee physicist who pioneered research in scintillation detectors. In the 1950s, Washington Square was home to one our deepest physicists, Bruno Zumino (b. 1923). Today, an active particle-theory group that includes Alberto Sirlin, a strong and recently augmented astrophysics group, a lively experimental particle-physics group, and small experimental atomic, optical, and condensed-matter groups are all housed at Washington Square.

Columbia University

If I were allowed to list only one physics site in New York City, it would have to be the Columbia University Physics Department. In a class by itself on the New York physics scene, it has had a glorious history that stretches back over a century – a period of time that perhaps is not so impressive by European standards, but is pretty impressive by American ones. Columbia's was not among the first physics departments in America, which included those of Harvard, Princeton, and Yale, but at some point it caught up to all of these, and arguably surpassed them, at least for a long stretch of time in the twentieth century. It has now been for decades a domain under the reign of T.D. Lee. Rather than overwhelm the reader with too much information, I simply point to Columbia's stellar accomplishments by listing below the Nobel Prizes won by Columbia faculty members.

Physics at Columbia probably can be dated from the establishment of the School of Mines in 1864, in particular with the appointment of Michael I. Pupin as professor in it. The Physics Department in the College of Arts and Science was established in 1892. The American Physical Society was founded at Columbia in 1899.* The present physics building, Pupin Hall (Fig. 13), was built in 1925 on the north edge of the main campus (by 120th Street). Unlike many other thriving physics departments, Columbia's to this day has not seen fit to move to snazzier quarters. Pupin Hall is now an official national landmark. Columbia's first Nobel Prize awarded to a regular faculty member went to Harold C. Urey (1893–1981), who received the Nobel Prize for Chemistry in 1934 for his discovery of deuterium three years earlier. In physics, beginning in the early 1930s, I.I. Rabi was the dominant figure. John S. Rigden has discussed Rabi's pioneering work on atomic and molecular beams, and that of his amazing coterie of students, in detail.[21] Other Columbia physicists also made stellar experimental and theoretical contributions to

* Columbia hosted the American Physical Society until it moved into its first fully dedicated headquarters at 335 East 47th Street in Manhattan, jointly occupied and owned by the American Institute of Physics (AIP). That building was demolished after APS and AIP sold it to the Republic of Korea. The building has since been replaced (naturally) by a larger building housing the South Korean UN embassy. And APS, AIP, AAPT, and AAPM (American Association of Physicists in Medicine) are all now comfortably ensconced in an attractive building in College Park, Maryland. The minutes of the first APS meeting state: "The first meeting of the Society was held in Room 304 Fayerweather Hall, Columbia University, New York City, on Saturday, May 20, 1899, at 10:30 A.M. The meeting was welcomed on behalf of the University by Professor M.I. Pupin."

Fig. 13. Pupin Hall at Columbia University. Photograph by the author.

nuclear and particle physics and astrophysics, as epitomized by the awards listed below. Finally, the basement of Pupin occupies a special niche in the history of physics, as this is where Herbert L. Anderson, Eugene T. Booth, John R. Dunning, Enrico Fermi, G. Norris Glasoe, and Francis G. Slack performed the first fission experiments in the United States on January 25, 1939. The following year, in March 1940, Dunning, Booth, and Aristid V. Grosse, using a small sample of the separated uranium isotopes supplied to them by Alfred O.C. Nier of the University of Minnesota, proved that U-235 is the fissionable isotope. The cyclotron they used was removed from the basement laboratory some years ago.

A thorough history of Columbia's Physics Department, which remains today a very active center of research, can be found at the websites < http://phys.columbia.edu/history > and < http://phys.columbia.edu/heritage.html > . I reproduce in Table 1 the list of 28 Nobel Laureates who have been associated with the department. Thirteen received the Nobel Prize for theoretical work, fifteen for experimental discoveries; ten were Columbia Ph.D.s in physics, and ten (denoted by an asterisk) performed their prize-winning research in Pupin Hall.

Table 1. Columbia University Nobel Laureates according to the year they received the Nobel Prize in Physics. EKA stands for the Ernest Kempton Adams Fund for Physical Research, which was established in 1904 by Edward Dean Adams "as a memorial to his son...who received the degree of Electrical Engineering in 1897 and Master of Arts in 1898, and who devoted his life to scientific research." Quoted in Max Planck, *Eight Lectures on Theoretical Physics delivered at Columbia University in 1909* (New York: Columbia University Press, 1915), p. iii. I thank Roger H. Stuewer for supplying this information. Asterisks refer to research performed at Columbia.

Year	Name	Association with Columbia
1902	Hendrik A. Lorentz	EKA Lecturer in Mathematical Physics, 1905–1906
1911	Wilhelm Wien	EKA Lecturer in Mathematical Physics, 1913
1918	Max Planck	EKA Lecturer in Mathematical Physics, 1909
1923	Robert A. Millikan	Columbia Ph.D., 1895 (first Physics Ph.D. awarded)
1938	Enrico Fermi	Faculty, 1939–1946
1944	Isidor I. Rabi*	Columbia Ph.D., 1927; Faculty, 1929–1967; Professor Emeritus, 1967–1988
1949	Hideki Yukawa	Faculty, 1949–1953
1955	Willis E. Lamb*	Faculty, 1938–1951
1955	Polykarp Kusch*	Faculty, 1939–1971
1957	Tsung Dao Lee*	Faculty, 1953-present
1963	Maria Goeppert-Mayer	Research Staff and Faculty, 1939–1946
1964	Charles H. Townes*	Faculty, 1948–1961
1965	Julian Schwinger	Columbia B.A., 1936; Columbia Ph.D., 1939
1967	Hans A. Bethe	Visiting Professor, 1948 and 1949
1969	Murray Gell-Mann	Visiting Professor, 1954–1955
1972	Leon N. Cooper	Columbia B.A., 1951; Columbia Ph.D., 1954
1975	Aage Bohr*	Research Staff, 1948–1949
1975	James Rainwater*	Columbia Ph.D., 1946; Faculty, 1946–1986
1976	Samuel C.C. Ting	Faculty, 1965–1969
1978	Arno A. Penzias	Columbia Ph.D., 1962
1979	Steven Weinberg	Faculty, 1957–1959
1980	Val L. Fitch	Columbia Ph.D., 1954
1981	Arthur L. Schawlow	Research Staff, 1949–1951
1984	Carlo Rubbia	Research Staff, 1958–1959
1988	Leon M. Lederman*	Columbia Ph.D., 1951; Faculty, 1951–1979
1988	Melvin Schwartz*	Columbia B.A., 1953; Columbia Ph.D., 1958; Faculty, 1957–1966, 1991-present
1988	Jack Steinberger*	Faculty, 1950–1969
1989	Norman F. Ramsey	Columbia B.A., 1935; Columbia Ph.D., 1937; Faculty, 1942–1946

Polytechnic University

New York never produced an engineering school of the caliber equivalent to the finest engineering schools in the country. It is difficult to understand why. There are important engineering schools at Columbia and City College, for example, and there used to be a fine engineering school at NYU at University Heights, which was dissolved in 1973, with many of its faculty members transferring to what was then Brooklyn Polytechnic. Perhaps, like the Massachusetts Institute of Technology (MIT) in the Cambridge-Boston area, what really was needed was a single, great engineering school in New York, rather than four or five smaller ones. The joining

of the NYU faculty members to those at Brooklyn Polytechnic was a step in that direction. In any case, the now-renamed Polytechnic University (website < www.poly.edu/brooklyn >) is the dominant engineering school in New York and has great strengths and considerable potential to become that single great school.

Polytech, founded in 1854, is the second oldest private engineering university in the country; it is located at 6 Metro Tech Center, a vibrant technology center on Flatbush Avenue in the heart of downtown Brooklyn. It is surrounded by other schools and a corporate park that is claimed to be the largest one in the United States. Polytech's physics department possesses several active research groups, most notably the Polymer Research Institute. Its dominance in research in polymer physics was established by Herman Mark (1895–1992) in the 1940s. Steven Arnold and his colleagues continue that tradition today. Isidor Fankuchen (1904–1964) also performed pioneering crystal-structure experiments at Brooklyn Poly. Another well-known establishment is the Weber Research Institute, which specializes in electromagnetic and electro-optical phenomena. To historians of science, one of Brooklyn Poly's best-known alumni is Bern Dibner (1897–1988), who received his bachelor's degree *cum laude* in electrical engineering in 1921 and became a noted industrialist, entrepreneur, rare-book and instrument collector, historian, and philanthropist. Recently, Polytechnic University was the recipient of one of the largest grants to a university in history, $175 million, by an alumnus, Donald F. Othmer.

The Manhattan Project

On June 28, 1941, President Franklin Delano Roosevelt established by Executive Order the Office of Scientific Research and Development (OSRD), whose Committee on Uranium was soon designated cryptically as the S-1 Section.[22] A year later, when the S-1 Executive Committee was seeking sites for its wartime work, one of the U.S. Army officers involved had established his headquarters in New York with the title Manhattan Engineer District – whence the origin of the official name of the Manhattan Project. On September 23, 1942, it was placed under the command of General Leslie R. Groves.[23]

New York remained as a locus for significant work in the Manhattan Project. As noted above, in 1939–1940 Columbia physicist John R. Dunning and his colleagues had carried out pioneering experiments on fission. Now, with the establishment of the Manhattan Project in the fall of 1942, Dunning took the lead in initiating research in Pupin Hall on the gaseous-diffusion method for separating the uranium isotopes. Other Columbia physicists, particularly Francis G. Slack, Eugene T. Booth, and Henry A. Boorse, also contributed significantly to this effort, as did Berkeley chemist Willard F. Libby and Minnesota physicist Alfred O.C. Nier, both of whom moved to New York to join Dunning and his colleagues to work for the Kellex Company, an independent subsidiary of the Kellogg Company that was created at the end of 1942 especially to carry out research on the gaseous-diffusion method. By 1943 this research took up all of the available space in Pupin Hall, and Dunning began to arrange for additional space elsewhere at the Bell Telephone Laboratories in New York, Princeton University, and the Kellex Plant in Jersey

City. The work of these physicists, and that of the many others who worked with them, was crucial to the ultimate success of the gaseous-diffusion method and its massive implementation at Oak Ridge, Tennessee, in 1944 and 1945.[24]

A Physics Stroll through Manhattan

It is impossible for a physical tourist to cover all of the major physics sites in New York in a single day. Distances in New York, unlike those in Paris for example, are sometimes rather daunting. Still, by excluding locations lying in the outer boroughs and restricting our tour to Manhattan, we can cover a good number of them by taking a bus or a subway now and then. It is quite easy to make estimates of distances in Manhattan, excepting the lower Manhattan and Greenwich Village areas. Twenty street blocks equal one mile, walkable in about thirty minutes if you obey the traffic lights – which, of course would set you off immediately as a tourist. Distances between avenues equals 2.5 city blocks, or 1/8 mile.

We start at the furthest uptown site and work our way downtown. We will skip Yeshiva University in Washington Heights, which on occasion has housed some very fine work, particularly in statistical physics. We will not include visits to the CCNY and Columbia University campuses; these should be visited on a separate tour on another day. We will not include the many superb medical centers (Columbian Physicians and Surgeons, Mount Sinai Medical Center, Sloan-Kettering Memorial, NYU Medical Center, and Montefiore in the Bronx), all of which have state-of-the-art radiation, diagnostic and clinical facilities that, of course, would have been impossible to achieve without physics research. Finally, we will not include the Hall of Fame for Great Americans on the former NYU University Heights campus, which can be visited by car or subway on a separate trip.

A good place to start our tour is the American Museum of Natural History (AMNH) on Central Park West and 79th Street. The AMNH (website $<$www.amnh.org$>$) possesses extraordinary anthropological, biological, and zoological collections – too many to see in a short visit. The most spectacular exhibit is the Rose Center of Earth and Space (Fig. 14).* This houses a new but already famous planetarium, which in less than thirty minutes gives a beautiful rendition of the heavens involving astronomy, astrophysics, and cosmology. There also are a number of other important exhibits; perhaps its spectacular gem and mineral exhibits (on the first floor, near 77th Street on the west edge of the main hall) would be of particular interest to condensed-matter physicists. You could spend a happy half-day wandering around the museum, then relax for the rest of the day, and continue your tour the next day on Manhattan's East Side.

Intrepid types intent on completing the tour in one day, however, could hop a cross-town bus at 79th street,** go to the end of the route on York Avenue, and

* Formally the Frederick Phineas and Sandra Priest Rose Center for Earth and Space. The planetarium is still called by its original name, the Hayden Planetarium, although it is completely new.

** Or walk across Central Park; this is a beautiful stroll that will take about half an hour.

Fig. 14. The Rose Center of Earth and Space of the American Museum of Natural History. Photograph by the author.

walk a few blocks south to the campus of Rockefeller University (website < www.rockefeller.edu >), whose entrance is at 1230 York Avenue around 66th Street. This famous university has no undergraduate school; it has a most distinguished faculty, including only six tenured physicists, at the time of this writing among whom are Albert Libchaber, Konstantin Goulianos, and Mitchell Feigenbaum, and a handful of graduate students. Abraham Pais (1918–2000) was on the faculty until his death.[25] Frederick Seitz (b. 1911), whose career in condensed-matter physics spans more than half a century,[26] still keeps an office there. A walk around the generously landscaped campus would be worthwhile, provided you can get past the guard at the entrance.

At 695 Park Avenue between 68th and 67th Streets you will find Hunter College, located in one of New York's highest rent districts, although its modern style of architecture clashes with its genteel surroundings.

Now proceed south to 63rd Street and then west almost to Fifth Avenue, where at 2 East 63rd Street you will find the elegant Italian Renaissance mansion housing the New York Academy of Sciences, formerly owned by the Woolworth family. You can wander through the building, perhaps introduce yourself to one of its friendly staff, and use the ancient, elaborately decorated rest rooms before continuing your stroll. (The NYAS had put the building up for sale, but it is now no longer on the block.)

The next stop, almost exactly one mile further south on Fifth Avenue, is the main branch of the New York Public Library (NYPL). The history of the NYPL is a wonderful New York story. It is one of those phenomenal institutions that was created by captains of industry and other philanthropists of the nineteenth century

who were set on making available to the "masses" without charge the full reservoir of our civilization as preserved in books. Today there are innumerable NYPL branches scattered about the city (except in Brooklyn and Queens, which have their own public libraries), but the 42nd Street library remains unique in its size and scope. Use of the library remains free. Guarded by two giant lions at its entrance (which on occasion have sported equally gigantic caps with the New York Yankees logo on them), one heads up the long flight of stairs into the vast lobby, thence to the third floor and the main reading room, recently beautifully renovated, also by the Rose family. There you either can browse the innumerable reference collections or use the online catalog to call up virtually any book of a non-technical nature ever published in the United States.* At any time there also are likely to be special exhibits scattered around the building.** Unfortunately, you cannot spend too much time here – you should proceed to the new Science, Technology and Business (STB) Library, dedicated fully to these specialized subjects. Accordingly, proceed further south on Fifth Avenue and one block east to Madison Avenue and enter the building that used to house the B. Altman department store. It now is the home of the STB library on the east and of the Graduate Center of CUNY, which encompasses all the senior colleges (CCNY, Brooklyn, Hunter, Queens, Lehman) on the west side, with its entrance at 365 Fifth Avenue. In the STB library you can access any journal or technical publication you can imagine, if there is a crucial one you have to consult during your stroll. You also can find non-technical publications such as old *Popular Science* magazines and their predecessors, going back to the early nineteenth century – great fun for browsing, although by now it's getting a bit late in the afternoon.

Almost two miles further downtown you will encounter the main building of Cooper Union, at Cooper Square, where Fourth Avenue and 8th Street intersect;*** you can usually wander into its famous Great Hall. A block west and two blocks south you will find the NYU Andre and Bella Meyer Hall of Physics at 4 Washington Place, and a further block south the elegant building housing the Courant Institute of Mathematical Sciences at 251 Mercer Street. You could finish your tour with a refreshing visit to Washington Square, which is virtually surrounded by NYU buildings, perhaps joining in with some folk singers or watching some gymnastic pyrotechnics.

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* Once as a student at CCNY I was doing a term paper on Benjamin Franklin; I called for "Poor Richard's Almanack," and within half an hour was handed a wrapped bundle of papers that turned out to be original issues! I imagine it would be harder to get these originals today, but I am guessing that it still could be done.

** Here's a tip for out-of-towners: the main reading room provides many full Internet-access outlets, without charge, although there sometimes is a wait to use them.

*** This is also the location of Astor Place, which loosely defines the entire neighborhood. It is the location of the former home of John Jacob Astor among other famous millionaires. The No. 6 (Lexington Avenue) subway still displays ceramic images of beavers, the Astor family trademark. See entry for Astor Place in ref. 28.

If you are still up to it, you might like to stroll west, almost to the Hudson River, then further south to 463 West Street, where you will see a massive apartment condominium, called Westbeth (Fig. 15),* which was developed with federal funds to house artists and their studios. This was the location of the great Bell Telephone Laboratories before moving to Murray Hill, New Jersey, in 1970. Opening in 1897, many early telephone and electronic inventions, including the first vacuum amplifier and oscillator tubes, were created here, and crucial condensed-matter research was performed here.[27] The first experimental talkie motion pictures also were made here in 1923, and Clinton J. Davisson (1881–1958) and Lester H. Germer (1896–1971) carried out their electron-diffraction experiments here in the mid-1920s. This is as fine a way as any to end our stroll. By simply turning around, and if the weather cooperates, you can see the glorious New York City sunset across the Hudson River. The site of the World Trade Center is about a mile further downtown, on your left.

Conclusion

Without the small number of far-sighted civic leaders who led the way, physics in New York City surely would have flourished anyway. Even so, it is inspiring to note how a few visionaries can make a difference. If I had to single out two, they would be Peter Cooper and Townsend Harris. Both had an intense belief in free education as the best way to help children from lower and middle-class families to

Fig. 15. Westbeth, 463 West Street. Photograph by the author.

* The name Westbeth results from a contraction of its location, at West and Bethune Streets.

live creative and fruitful lives. They represented the best of New York, but they also serve as symbols for the multitude of other idealistic and far-sighted business leaders, teachers, and parents who contributed so much to the environment described in this article.[28] And, of paramount importance, from the very beginning the arms of America embraced and welcomed the magnificent influx of talented people, physicists and others alike, into New York and beyond.

I know of no better way to end my article than to reproduce the Ephebic Oath, a pledge made by incoming students at Townsend Harris High School and, at many other high schools and colleges in the city. This oath was administered to young males in ancient Athens, and it is now administered to all entering freshmen at Townsend Harris. It is particularly appropriate at this time, after the September 11 attack on New York City:

> I shall never bring disgrace to my city, nor shall I desert my comrades in the ranks; but I, both alone and with my many comrades, shall fight for the ideals and sacred things of the city. I shall willingly pay heed to whoever renders judgment with wisdom and shall obey both the laws already established and whatever laws the people in their wisdom shall establish. I, alone and with my comrades, shall resist anyone who destroys the laws or disobeys them. I shall not leave my city any less but rather greater than I found it.

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