CHAPTER 1

A prodigy and his family have a narrow escape

Peter Lax was born in Budapest, Hungary, and lived there for his first fifteen years, when with his family he escaped to the United States in time to avoid the Holocaust. He has lived in the U.S. since 1941 and has long been thoroughly Americanized, but still cherishes his heritage of Hungarian language and culture. Therefore, it is necessary to start his biography with essential background: the strange and fascinating history of the Magyars.

The Hungarian nation and its language are often called "Magyar". The Hungarians or Magyars entered Central Europe from Asia in the ninth century. Their language has always set them apart, for it is neither Slavic like Czech or Polish nor Germanic nor Romance. In the middle of Europe, with neighbors speaking German or Romance or Slavic languages, Hungarians speak a "Finno-Ugric" tongue distantly connected to Finnish, Estonian, and to small populations in Siberia. There are hardly any commonplace Hungarian words whose meaning can be guessed even if you know English, French, German, and Latin. (I once attempted attending a class in Hungarian for beginners, but I was soon defeated.) An educated Hungarian must be bilingual, for rare is the non-Hungarian who will speak Hungarian.

Hungary was converted to Christianity early. The majority of its population are Roman Catholic, and the cardinal and his bishops play a powerful and malignant role in Hungarian politics. Hungary was affected by the Protestant Reformation, and a substantial minority of the population are Lutherans or Calvinists. There are also Jews.

Like its neighbors Romania, Bulgaria, Serbia, Croatia, Slovenia, Albania, and Greece, Hungary for a time fell under the Ottoman or Turkish Empire. For one hundred fifty years the central part of Hungary was ruled by the Ottoman Turks. The Turks had conquered the Byzantine Empire, which was the relic of the eastern half of the Roman Empire. In a famous battle in 1683, the Holy Roman Empire, whose capital was Vienna, turned back the Ottoman invaders. As a consequence, Hungary became subject to the emperor of Austria. Hungary was then three times as big as today. It included not just Magyars and Jews but also Romanians, Serbians, Croatians, Rusyns, Germans, and Slovaks. It had access to the sea by an Adriatic coastline and many large productive plains where grain grew and cattle were raised. The land was divided among large estates owned by Magyar noblemen, who lived richly from the labor of oppressed peasants. Like noble landowners in other countries, these Magyar rulers loved hunting deer and boar and being soldiers. Rarely were they scholarly or businesslike. One famous noble family, the Esterházys, were patrons of Joseph Haydn, the friend of Wolfgang Amadeus Mozart and teacher of Ludwig von Beethoven. The Esterházys could easily afford their own private orchestra and composer. In western Europe, Hungary was known as a wild, romantic, less civilized country, with incredibly rich noblemen. The operetta *Die*

Fledermaus by Johann Strauss Jr. centers on a fancy-dress ball given by a fantastically rich Hungarian count who lives in Vienna on the income from his huge Hungarian estate.

In old Hungary, Jews were peddlers, tavern keepers, teamsters, tailors, shoemakers. Some rabbis, of course, and some estate managers, bookkeepers, moneylenders. They lived in their city districts ("ghettos"), with their ancient religion. Noncitizens, without civic rights. At the end of the eighteenth century they were by and large emancipated by the liberal emperor Joseph II.

In 1848 Europe was shaken by revolution. Across the continent, people struggled to break from shackles that had been imposed by Russia, Austria, and Prussia after the defeat of Napoleon. Hungary tried to escape its domination by Austria's Habsburg emperor, but its war of independence was lost when Russia came to aid Austria. Then in 1867, after losing a war with Prussia and while struggling against the rising nationalism of his Balkan subjects, the Habsburg emperor in Vienna made a deal with the Hungarian aristocrats and upper classes. In return for their support of his rule, he promoted the Magyars to partners. His empire became an Austro-Hungarian Empire, with Budapest a second capital after Vienna. The empire became "the double crown". Hungary was allowed self-government, except for foreign policy and the military. The Magyars became Austria's agents, suppressing oppressed nationalities between the Carpathian Mountains and the Adriatic Sea. This arrangement was ever after called the *Ausgleich* (the Compromise). And the Jews became allies of the Austrians and the Hungarians.

The economic development of the mid-century and the *Ausgleich* opened the door for Hungary to enter the modern age of industry and commerce. But to do so required entrepreneurs—energetic people who knew how to innovate, how to modernize, how to take risks. Who was capable of constructing a modern metropolis for a still agrarian country? Most Magyar nobility had neither inclination nor preparation for commerce. They were known to take pride in letting hirelings do the work. The Magyar peasant was not about to found a business or enter a profession. Together with some German immigrants and the more enlightened section of the Magyars, it was left to the Hungarian Jews to make Budapest the exciting, dynamic capital of modern Hungary. They were granted citizenship, they could move to Budapest, they could start businesses, they could enter the professions! The Hungarian Jews responded eagerly. They became passionate Hungarian nationalists, deeply loyal to the Magyar nation and to its Hungarian king/Austrian emperor. They proudly declared themselves Hungarians first, Jews second.

By 1900, Budapest was comparable to New York—a busy center of commerce, with vibrant journalism, theater, art and music. There was a brilliant literary flowering. It had the largest stock exchange in Europe and the most grandiose parliament building in the world.

"Booming Budapest of 1903, into which Johnny von Neumann was born, was about to produce one of the most glittering single generations of scientists, writers, artists, musicians, and expatriate millionaires to come from one small community since the city-states of the Italian Renaissance. In much of 1867–1913, Budapest sped forward economically faster than any other city in Europe, and with the delights that a self-reliant plutocracy (rather than self-questioning democracy) temporarily brings. Budapest surfed into the twentieth century on a wave of music and operetta down the blue Danube, as an industrializing city that 'still smelled

Photograph by Civertan Grafikai Stúdió, Hungary

Heroes' Square, Budapest–a World Heritage Site to the 1000-year history of Hungary

of violets in the spring,' pulsing with mental vigor in its six hundred cafes and its brilliant elitist schools." (Norman Macrae, quoted by George Marx, page 267.)

"Budapest rivaled Paris and Vienna in first-class hotels, garden restaurants, and late-night cafes, which were hothouses of illicit trading, adultery, puns, gossip and poetry, the meeting places for the intellectuals and those opposed to oppression. It was an Old World city, its women praised for their beauty and its men for their chivalry." (Paul Hoffman, *The Man Who Loved Only Numbers*, quoted on page 280 of Marx.)

Jews were prominent. Many took Magyar names. Among famous mathematicians, Weisz became Fejér, Politzer became Peter. Jewish bankers and industrialists became nobles and barons, with hereditary titles. The famous mathematicians John von Neumann and Theodore von Kármán inherited their honorific "von" from their ennobled fathers. Theodor's father, Mor, was instructor of the crown prince and a reformer of education.

As in Paris, London, and Berlin, the period before World War I in Budapest was later remembered nostalgically as a lost time of bourgeois prosperity, stability, and optimism. This prosperous comfort was of course based on the misery of an industrial proletariat and a downtrodden peasantry. But for the striving middle class, there was good music and literature and a pleasant culture of theaters, newspapers, concerts, and coffee houses.

One famous Jewish family were the Kornfelds, whose dynasty was founded by the banker Zsigmund (1852–1909). He was the grandson of Aharon Kornfeld, the last great head of a yeshiva in Bohemia. He came as a youth from Vienna in 1878 to run the Rothschild banking empire's branch in Budapest. Only twenty-six years old, he was chosen by Albert Rothschild to be director of the Hungarian General Credit Bank in Budapest.

His bank founded and reorganized industrial companies, including a mining company in Bosnia and an oil refinery in Fiume (now Rijeka, Croatia). He participated in founding the Budapest-Pécs Railway, the Electric and Transportation Share Company, and the Hungarian River Navigation and Maritime Share Company, of which he became president. In 1892 he was instrumental in a currency reform. In 1900 he became the managing director of his bank, and in 1905 the president. In 1899 he was elected president of the Budapest Commodity and Stock Exchange, where he made Hungarian replace German as its official language. In 1909 the Emperor Franz Joseph gave him the title of baron.

The First World War resulted in catastrophic losses for Hungary and Hungarian Jews. The Austro-Hungarian or Habsburg Empire, along with Prussian Germany and Ottoman Turkey, was defeated by England, France, and the U.S. (The other "ally," the czar of Russia, had been knocked out of the war by the Bolshevik Revolution.) The Treaty of Trianon, imposed on Hungary by the victorious Allies, liberated the formerly oppressed nationalities of the Austro-Hungarian Empire by creating two new states, Czechoslovakia and Yugoslavia, and giving the large province of Transylvania to Romania. Hungary was reduced in size to one third, lost much productive farmland, and was landlocked, cut off from the Adriatic Sea. Many Magyars became minorities living in Czechoslovakia, Yugoslavia, or Romania. For decades afterward, Hungarian schoolchildren started each day by chanting, "Nem, nem, soha!" (No, no, never!) (Never accept the loss of Hungarian territory, the Treaty of Trianon!)

The destruction of the Austro-Hungarian Empire and the punitive Treaty of Trianon were followed by two more disasters. A Hungarian prisoner-of-war in Siberia named Béla Kun became a follower of Lenin and returned to Budapest to lead a four-month Bolshevik revolution. Homes and businesses of the rich and prosperous were expropriated. New radical officials took government office. Kun himself and many of his prominent followers were Jews (although of course nonobservant and not connected to the official Jewish community of Budapest). Many of the homes and businesses that they expropriated had been owned by prosperous Jews. This experience left long and bitter hatred of communism or socialism among many middle-class Budapest Jews.

After four months, the Bolshevik regime in Budapest was destroyed by an invading army from Romania. Hungary was restored as a "kingdom" without a king. A Magyar admiral named Miklós Horthy was appointed "Regent" and would rule Hungary for three decades. His regime was destroyed by the Nazis, and then by the Soviet army, at the end of the Second World War.

Horthy's regime was a nondemocratic, authoritarian system. It started out with two years of White Terror, taking merciless revenge on the Bolsheviks and on their Jewish supporters and sympathizers. Béla Kun escaped to Moscow as a leading "functionary" in the Communist International, to be executed years later in one of Josef Stalin's fits of murderous paranoia. (Kun's grandson Miklós returned from Russia to Hungary and is a historian there, a specialist in "Kremlinology"—the private life of Josef Stalin.)

The Horthy regime was unremittingly plagued by the "Jewish question". Throughout the 1920s and 1930s, anti-Semitic policies and political parties grew more prominent. In 1929 came the worldwide stock market crash and subsequent Great Depression, with a terrible crisis of unemployment and deprivation. The

Arrow Cross Leader Ferenc Szálasi, 1944

scapegoating of Jews intensified. As the 1930s and 1940s advanced, so did horrifying fascism and anti-Semitism in both Hitler's Germany and Horthy's Hungary. In Hungary arose a Nazi-type anti-Semitic party, "Arrow Cross". Their disgusting and frightening signs and slogans multiplied, their power and influence grew.

Horthy imposed quotas on Jewish professors and students at the university and restricted Jewish participation in the professions and the civil service, but he continued faithfully to respect private property and capital. Major armaments industries continued to be owned and run by Jews. Major publishing companies, theaters, and coffee shops were still owned and patronized by Jews. The Jewish population of Budapest was around 30 percent. The prosperity, glamour, and brilliance of Budapest life were to a great extent created by Jews, who were prominent in banking, industry, journalism, law, and medicine. Until the Nazi clamp-down in the last months of the Second Great War, a major, almost dominating, role in the city continued to be played by Jewish professionals and capitalists.

Around 1936 the desire to recover its lost territories pushed Hungary towards the German-Italian axis. Anti-Semitism was already widespread in Hungary, and closer ties with the Nazis made the situation much worse. Anti-Jewish laws were passed, partly to please Hitler. The Catholic hierarchy and the Magyar nobility had formerly accepted the "over-talented, over-prosperous" Jews as allies against the other nationalities. But now Jews came to be seen as outsiders who had somehow grabbed more than their fair share. No matter how thoroughly the Jews Magyarized themselves—even becoming champion fencers and water polo players—they were seen as just not really Magyars.

In 1938 and 1940 Hungary seemed to be achieving its territorial objectives when the Vienna Awards returned some of its lands. In 1939 World War II began, but Hungary stayed out of it until 1941, when it joined the war against Russia on the side of Germany. By then, Hitler had ghettoized and imprisoned the whole German Jewish population, conquered Czechoslovakia, split Poland with Josef Stalin, and overrun Belgium, Holland, Denmark, Norway, and France.

To these events, the dominant leadership of the Hungarian Jews and the bulk of their population responded by declaring themselves more and more Hungarian. (And of course a substantial portion of Hungarian Jews took comfort and refuge in their religion.) Zionist and socialist alternatives did not become influential. After all, they were faithful, loyal Hungarians! They did not recognize that their prewar status as needed defenders of the status quo had disappeared. There still remained in Budapest a large, vibrant Jewish community that produced famous writers, musicians, and scientists.

A very prominent Jewish publisher named Vészi was a friend of Peter's father. As a child Peter played with cousins on a large estate belonging to Vészi. When he revisited it decades later, it had fallen into ruin.

The Holocaust

On March 19, 1944, Berlin got wind of cease-fire talks between Hungary and the Allies. German troops occupied Hungary. Accompanying the German army was a special unit (*Sondereinsatzkommando* (SEK)), commanded by SS Lieutenant Colonel Adolf Eichmann, with orders to "dejewify" the country.

The SEK was a force of about one hundred people, including twenty officers, and drivers, guards, and secretaries. Without help, these one hundred Germans could not annihilate 770,000 Jews scattered all over Hungary. Regent Miklós Horthy appointed a new government to serve the Nazis, led by Döme Sztójay. Between mid-April and late May, in the largest deportation ever achieved during the Holocaust, practically the entire Jewish population of the Hungarian countryside was ghettoized. Between May 15 and July 9, over 437,000 of them were delivered to Auschwitz.

By early July 1944 only Budapest Jews and those serving in labor service units were still in Hungary. Then the deteriorating war situation and the spreading news of mass extermination convinced Horthy to try to stop the deportations and escape from the German alliance. So on October 15 the Germans forced Horthy to resign and gave power to Ferenc Szálasi of the Arrow Cross movement. In November and December 50,000 more Jews were taken to Germany, most of them driven there on foot. The Jews who remained in Budapest were locked into two ghettos where Arrow Cross militia murdered thousands of them.

Between 1941 and 1945 more than half a million Hungarian Jewish men, women, and children were destroyed on the streets of Budapest, in countryside ghettos, behind barbed wire in German concentration camps, and in gas chambers.

Lax family

Before all these calamities, Peter Lax's family lived a happy and prosperous life in Budapest. (The name "Lax" is the same word as "lox", the familiar New York snack. It just means "salmon".) His father, Henrik, was an internist, and his mother, Klara, after training as a pediatrician switched to clinical pathology and ran Henrik's laboratory. Henrik and Klara met in medical school. Peter thinks Klara may have been one of the first women admitted to medical school in Hungary. Henrik was chief of medicine at the Jewish Hospital in Budapest and famous as a brilliant diagnostician. His patients from high society included the playwright Ferenc Molnar, the composer Béla Bartok, the film magnate Sir Alexander Korda, and the Swedish actress Greta Garbo. Molnar would later serve as the Lax family's

Peter and his brother John in their childhood in Hungary

sponsor in the U.S. (Someone had to promise to support them financially if ever they became charges on government charity!) Korda expressed his appreciation of Henrik's treatment by a gift of the painting *Waterloo Bridge* by the French impressionist Monet. (Worth $10,000 in 1952, it ultimately turned out to have a truly incredible cash value.)

Henrik told Peter about one of his most impressive cases. A diabetic patient was approaching death, even though the insulin Henrik prescribed should have maintained her. Henrik brilliantly solved the mystery: her husband was diluting the dose in order to murder her! However, Doctor Lax was not rewarded by the patient's gratitude. On the contrary, she reconciled with her would-be murderer and changed doctors!

Peter was born on May 1, 1926. He had an older brother, John, as well as a cook and a *fraulein* or nanny. It was customary to hire a young Austrian woman for child care, benefitting the child by exposure to the German language. Peter says, "My brother and I had a series of nannies; we were rather undisciplined, so they quit, except the last one, who stayed for five years. She survived the war and afterwards emigrated to Australia. We kept in touch with her."

The family life was taken up with socializing, listening to fine music, and playing tennis. They were Jewish by descent but not at all observant. Peter's paternal grandmother in her youth had been a suffragette!

Peter early displayed a talent for numbers. His mother always liked mathematics, and her cousin was married to a famous young mathematician, Gabor Szegö. Mathematicians refer to the 1920s and 1930s in Hungary as "the Hungarian miracle". There were the exceptionally brilliant John von Neumann and the brothers Frigyes and Marcel Riesz, the collaborators George Pólya and Gabor Szegö, Leopold Fejér, Cornelius Lanczos, Bela Szőkefalvi-Nagy, Arthur Erdelyi, Paul Erdős, Dénes König, Rózsa Péter, Michael Fekete, Paul Turan. Of this list, all but Szőkefalvi-Nagy were Jewish!

Janos Bolyai, one of the creators of non-Euclidean geometry in the early nineteenth century, was a hero of Hungarian culture, even though in his own lifetime he was totally ignored. Two educational institutions helped greatly in fostering young Hungarian mathematicians. A high school math newspaper, *The Mathematics Journal for Secondary Schools* (*Középiskolai Matematikai Lapok*), founded in 1894 by Daniel Arany, published mathematical problems and solutions. The possibility of getting one's name in the paper fostered a great spirit of friendly competition among young problem solvers.

And there was a problem-solving contest for high school graduates, called the Eötvös Competition, in honor of Baron Lorand Eötvös. He was a leading physicist, internationally recognized for precise measurements of the gravitational force. Many future Hungarian mathematicians and physicists were prizewinners in the Eötvös Competition.

Peter thinks some credit for the Hungarian Miracle should go to an earlier Hungarian mathematician, Julius König. He was a student of Leopold Kronecker, made an important contribution to Cantor's set theory, and was influential in nurturing mathematics in Hungary. His son, Dénes, is considered the father of modern graph theory. Dénes befriended and encouraged Peter and sent a letter of support to John von Neumann.

Peter likes to tell how Leopold (Lipot) Fejér, the first Jew proposed for a professorship at Budapest University, won his appointment there. "At that time there was a very distinguished Jesuit theologian, Ignatius Fejér, in the Faculty of Theology. One of the opponents, who knew full well that Lipot Fejér's original name had been Weisz, asked pointedly: 'This Professor Leopold Fejér that you are proposing, is he related to our distinguished colleague Father Ignatius Fejér?'

Rózsa Péter (1905–1977)

And Lorand Eötvös, the great physicist who was pushing the appointment, replied without batting an eye: 'Illegitimate son.' That put an end to it."

Peter's uncle Albert Korodi, his mother's younger brother, an engineer by profession, was "a terrific mathematician." (He had changed his name from Kornfeld.) At eighteen he won the mathematics prize in the Eötvös competition. That year Leo Szilard won the physics prize, coming in second after Korodi in mathematics. Szilard and Korodi became very good friends.

Szilard is famous for first conceiving of a chain reaction of uranium fission. He made important inventions, including patent applications for a linear accelerator in 1928 and a cyclotron in 1929. He worked with Albert Einstein to develop a refrigerator that had no moving parts. It wasn't commercially successful, but it turned out to be useful in experimental physics. Peter's uncle Albert Korodi did the engineering design for the Einstein-Szilard refrigerator.

According to the Hungarian physicist George Marx, who heard the story from Korodi (*The Voice of the Martians*, page 213, Akademai Kiado, Budapest, 2001), "Szilard's most famous invention was that a household refrigerator would last longer

Dénes König (1884-1944)

Courtesy of Rényi Institute of Mathematics, Hungary

if the compressor pumps had no rotating solid parts subject to abrasion. He wished to use the Lorentz force, exerted by a static magnetic field, on direct current flowing through mercury, to drive the liquid metal around. He asked Albert Korodi, his friend since their simultaneous winning of the Eötvös Competitions, to develop this idea. Korodi was studying engineering in Berlin and made detailed plans and calculations, with the conclusion that the efficiency of the magnetic compressor would be very low, due to the modest electric conductivity of mercury, compared to that of copper. A week later, Szilard turned up again, suggesting the use of a eutectic mixture of sodium and potassium, liquid at room temperature and making a good conductor. Practical studies by Korodi showed that sodium and potassium were too abrasive, attacking the insulation of the wires conducting the electric current in the airtight container. Szilard complained to Einstein about his difficulties. After a few minutes of thinking, Einstein proposed an arrangement in which the current was closed through an air gap within the container, thus the corrosion of the insulator could not endanger the vacuum-tight enclosure of the aggressive liquid metal. Einstein agreed to patent the magnetic compressor under the names of Einstein and

Szilard, possibly helping to improve Szilard's financial position. Szilard convinced *Allgemeine Elektrizitatsgesellschaft* to build a prototype of the magnetic refrigerator. The company hired Albert Korodi to construct the machine. The practical efficiency of the fridge turned out to be still too low, therefore the system did not catch on. But liquid sodium driven by a magnetic pump is used nowadays to cool high temperature reactors, especially the breeders."

In 1939, living in the U.S., Szilard learned that physicists in Germany had achieved nuclear fission. Terrified at the possibility of a Nazi atomic bomb, he used his friendship with Einstein to alert President Roosevelt to the importance of an atomic bomb. As a remote consequence, five years later Peter Lax, then a private in the U.S. Army, would find himself assigned to something called the Manhattan Project in Los Alamos, New Mexico.

Peter learned a lot from his uncle Albert. "When I was about twelve I learned from him that, by the distributive law, -1 times -1 equals $+1$. I thought that was great. I remember my mother describing what a shock it was, when her younger brother came along, to realize on what a higher level mathematics can be understood. She remained quite interested in mathematics, and my father respected it from afar.

"My uncle Victor Farkashazi was a pediatrician, and he had a deep interest in mathematics. I still remember two wonderful problems he posed. Here is the first:

"A gold merchant wants to buy gold dust from gold miners in multiples of 1 ounce, up to 40 ounces. He has an old-fashioned kitchen balance to weigh the gold dust. Question: how many weights does he need? (Today the story would be told about a cocaine merchant.)

"And here is the second: A spider is sitting on the ceiling of a room, 1 foot from one wall, and 5 feet from the other wall. Its nest is located on the other wall, 1 foot from the first wall and 6 feet from the ceiling. She needs to get to her nest as fast as possible (I forget why). Question: what path does the spider take?

"What I like about these problems is that they illustrate basic mathematical principles."

Peter became very interested in math when he got to the Gymnasium, the famous *Minta* (Model School). It was founded as a teacher-training school by Mor Kármán at the suggestion of the minister of culture, Jozsef Eötvös, father of the physicist Lorand Eötvös. Other graduates of the *Minta* include the great aerodynamicist Theodore von Kármán, who was Mor Kármán's son, the chemist-philosopher Michael Polányi, and the H-bomb physicist Edward Teller.

Peter's parents provided him with a private tutor in mathematics. There were in Budapest quite a number of unemployed brilliant young mathematicians, mostly Jewish. Agnes Berger, a university student whose parents were physicians and close friends of Peter's parents, made the perfect suggestion for Peter's tutor: Rózsa Péter. Ultimately, Dr. Péter became famous for two books: a treatise on the branch of logic called "recursive functions" and a beautiful popularization of mathematics, *Playing with Infinity.* But in the Hungary of the 1930s, as a Jew, she was not eligible for a professorship at the university.

"Rózsa Péter was wonderful," he says. "She was immersed in mathematics. She was interested in how people think. The very first thing we did was to read *The Enjoyment of Mathematics* by Rademacher and Toeplitz. I was twelve or thirteen." This famous classic is perfect for a young beginner attracted to mathematics. It takes up a series of independently attractive topics in algebra, geometry, number theory, and logic in a challenging yet accessible style.

With Rózsa Péter he went through *The Enjoyment of Mathematics*, mastering numbers, curves, algorithms, and proofs galore. Sometimes she would ask him before they read a proof, "Can you do it yourself? Next week when you come, try to do it."

"I went to her house maybe twice a week for a couple of years, until I left Hungary at fifteen and a half. Sometimes she would take me to meetings of the Mathematical Society. I was the youngest. I was a little shy, but I went anyway. At one meeting someone was presenting Robbins' theorem on directing the edges of a graph so you can get from any point to any other point. The theorem says you can do that unless the graph can be disconnected by removing a single edge. The last lecture I heard was Hajós presenting his solution of the Minkowski problem about paving space. I didn't really understand it."

As the 1930s and 1940s advanced, two things in the life of the Lax family grew larger and larger. The first was young Peter's wonderful gift for mathematics. The second was horrifying anti-Semitism in both Hitler's Germany and Horthy's Hungary. By 1941 Hitler had conquered France, and war with Russia was coming next. What to do?

No place in Europe was safe. They would have to cross the ocean to America. And America wasn't very welcoming to refugees. The Great Depression wasn't over yet. There was resistance to foreigners who might take jobs away from Americans. And anti-Semitism was far from unknown in the U.S. It was considered advanced and liberal, that the patrician president, Franklin Delano Roosevelt, a distant cousin of former president Theodore Roosevelt, had chosen as his Secretary of the Treasury a Jewish banker, Henry Morgenthau. Some people called the president "Rosenfeld", as a term of abuse and hatred. Many European Jews trying to flee Hitler were unable to obtain U.S. visas.

Fortunately, Dr. Henrik Lax had patients and friends from the U.S. Peter says, "There was an American who had visited Hungary a few years before. He had been in an accident and my father had saved his life. He sent an affidavit. And also the American consul in Budapest was a patient of my father's."

It's not easy for a successful physician to abandon his patients and hospitals, and his prestigious, comfortable life to run to a strange country. Klara Lax insisted, demanded, that they escape while they could. Some who could have done so delayed too long. One such was Ferenc Polgár, Henrik's colleague at the Jewish Hospital, where he was chief of radiology. It was especially hard for a radiologist to abandon his cherished X-ray machines. Polgár and his family nevertheless did survive, fortunately for me.

"At that time," says Peter, "America to me was a child's dream. I really didn't know English, although I had studied it for two years. What did I know about America? Skyscrapers, tap dancing, Hollywood, chewing gum, and the electric chair. As children we were fascinated by the idea of an electric chair. I had read *The Last of the Mohicans, Tom Sawyer*, and *Huckleberry Finn*, and a novel by Jack London about two dogs that could sing—you know, sort of howl. I had also read *Helen's Babies* and *The Diary of a Bad Boy.* All were in Hungarian translations."

He says his English tutor in Budapest was wonderful. "He didn't assign childish reading; he assigned adult reading." Peter read the short stories of Somerset

Maugham, who was then widely read and highly respected. Maugham is not so much talked of anymore, but Peter says people should still read him; he is a first-class writer.

In 1940 Rózsa Péter suggested that Peter take the Eötvös Competition, even though Peter was only fourteen years old and it's restricted to high school graduates. His participation had to be unofficial. The regular participants sit in a closed room, watched by proctors, to work on three contest problems. The first question is usually easy, the last is never easy. Peter walked over to the university, found the contest room, received the three problems, took them home, did them, and turned them in the next day. All three answers were perfect.

Again the next year, 1941, at age fifteen, a few months before the Lax family departed from Budapest, he did it again. Unofficial participation and perfect score.

Here is the third problem from 1941: "ABCDEF is a hexagon inscribed in a circle. Suppose that the sides AB, CD, and EF have the same length as the radius. Prove that the midpoints of the other three sides form an equilateral triangle."

Sixty years later, during his acceptance speech for the Abel Prize in Oslo, Peter said that in his youth in Hungary, "Problem solving was regarded as a royal road to stimulate talented youngsters. I was very pleased to learn that here in Norway they have a successful high-school contest, where the winners were honored this morning. But after a while one shouldn't stick to problem solving. One should broaden out. I return to it every once in a while, though."

A few months after his second success on the Eötvös Competition, Peter joined a math study group at the Jewish Gymnasium. Laszlo Fuchs, a Hungarian-American algebraist now retired from Tulane University, was in that group with Peter. He writes, "At the beginning of the 1941–42 school year, Paul Erdős's father visited the principal of the Jewish Gymnasium in order to secure a classroom. The Jewish Cultural Association had organized a special course for high school students interested in mathematics, and needed a place to meet once a week. The instructor was Tibor Gallai, a very talented mathematician and a superb teacher (without a job). The school principal agreed, under one condition: his son (me) would also be admitted to the course. Peter Lax was the youngest one of 8 or 10 students in the group. Most of us were in high school. Some had already graduated, but because of the *numerus clausus* (quota against Jews) weren't allowed to enter the university.

"Before and after class we had long discussions on the solutions of the take-home problems, possible generalizations, and so on. Peter participated actively, and it was clear that he knew more mathematics than most of us. He left a couple of months later, when his family immigrated to the U.S. We were extremely sorry that he wouldn't come to the class any more, but we were happy for him that he could leave the country. He was one of the few in the course who would survive the Holocaust."

Indeed, the Lax family had tickets for the November 25 train to Lisbon.

Rózsa Péter and Dénes König wrote letters to mathematicians in the U.S., calling attention to Peter's exceptional promise.

Peter writes, "Dénes König wrote to John von Neumann, Gabor Szegö, and Otto Szasz asking them to look out for me. Only three years later he killed himself, to avoid arrest and deportation by the Nazis."

König's letter to von Neumann is dated November 12. Here is a translation into English:

> My dear friend,
>
> It is my understanding that Dr. Henrik Lax, a physician from Budapest, is moving with his family to America within the next few days. He is taking with him his son Peter Lax who is a gymnasium student in the VI grade. I have been in mathematical contact with young Peter for more than a year. Based on personal conversations and on his computational work (which consisted of solving basic mathematical problems) I have become convinced that the young man possesses extraordinary talent in mathematics. For instance, for two successive years, he succeeded in solving the tasks administered during the Mathematics and Physics Society's competition at a much higher level than those students who were the official participants. It should be in Peter's interest, but also in the interests of the community, if this exceptional talent were to be further nurtured and supported. Thus I am asking you, that if and when Peter Lax approaches you with some questions or requests for advice, would you please respond to him with the good will appropriate for a future scientist.
>
> With great respect and friendship,
> Dénes König
> Budapest, XI
> Horthy Miklós ut. 28

Three years later, in the days of Arrow Cross terror before the liberation of Budapest, "when the German army occupied Hungary, putting Hungarian Nazis in power, König saw what was coming and threw himself out the window of his apartment" (Lax, *Functional Analysis*, page 159).

So the Lax family got their papers and on November 25, 1941, they boarded the train from Budapest to Lisbon, Portugal, where they had tickets for a steamship to New York City.

As the Laxes traveled through Nazi Germany, they shared a train compartment with *Wehrmacht* soldiers. "When we reached the Swiss border," Peter later remembered, "the German guard checked our papers, and then said, 'Just a moment.' The air froze for us. But to our relief, he only asked if we still had the ration coupons for meat and butter that we had received on entering the Reich. My father gladly gave him the coupons."

Their ship departed Lisbon on December 5, 1941, the last U.S. passenger ship to leave Europe for the next four years. They were in the Atlantic Ocean when Japan bombed Pearl Harbor two days later. Now the U.S. was at war with the Hitler-Mussolini-Tojo axis, and Hungary, an ally of the Axis, was a wartime enemy of the U.S. But young Peter wasn't wasting his time on board ship. While they were crossing the Atlantic, he taught himself calculus. When they arrived in New York, they were at first classified as enemy aliens and taken to Ellis Island but released after a few days.

In the next four years, more than two thirds of Hungary's Jews, including many of the Lax family's relatives, friends, and neighbors, would be murdered by the Germans or by their Arrow Cross friends.

"We were the only members of my family who escaped the war in Europe. Of the ones who remained behind, my uncle Imre, my mother's brother, was killed while in a labor battalion. Another uncle, the husband of my mother's sister, Dr. Victor Farkashazi, and his son Steven, were murdered by Hungarian Nazis in Budapest. His wife and younger son escaped and eventually ended up in the U.S. His son is my cousin Bill Farr (he abbreviated the name Farkashazi), a retired tool-and-die maker. He worked for many years for General Motors. He has five talented children.

"When General Motors was contemplating reducing the pension and health care benefits of its retired workers, I asked my cousin if he was worried. He answered, 'I haven't worried since 1944.'

After the defeat of Hitler, Peter went every other year to visit Hungary, where he had three surviving cousins and mathematical contacts. His parents sent packages and money to their relatives and visited Hungary as soon as possible. Peter's father, Henrik, brought his mother to New York, where she lived for twenty years until the age of ninety-four.

"She was a remarkable woman," writes Peter, "an early suffragette. Her husband died when she was 38, and after that she supported herself and her children by a sewing business. She survived the war hidden in a hospital run by one of my father's closest friends, Dr. Géza Petenyi, whose name is inscribed in Jerusalem on the list of righteous gentiles.

"He saved the lives of others, one of them a very close friend of mine. He was being deported; but he managed to telephone Petenyi and tell him what road the deportees were on. Petenyi hailed a taxi and followed the column. When they made a rest stop, he got out of the cab, walked up to my friend, and said: 'Walk very slowly with me to that taxi over there and get in.' They got away."

But Peter's father, Henrik, never forgave the Hungarians for what they had done. When Henrik went back to Budapest to fetch his mother and visit his sister, he never stepped out of his hotel. After his sister died, he never went back again.

After the suppressed Hungarian revolution of 1956, the Soviets let Kadar liberalize the regime and allow people to travel to the West.

"My father's sister and her husband managed to get out in 1957 and settled in New York. They prospered; he was a very successful accountant. She lived to be 93 years old. There is longevity in my father's family; he lived to be 95."

CHAPTER 2

Manhattan, NY, and Manhattan Project. An army private among the "Martians"

In the U.S. the Lax family contacted Klara's cousin's husband, Gabor Szegö, at Stanford University. "My mother and Mrs. Szegö were first cousins, and our families had been friendly in Hungary. When we came to America, the friendship was renewed. They were very nice to me."

They also contacted von Neumann. "Von Neumann was always very kind to me." Von Neumann visited Peter at home and advised him to get in touch with his collaborator Francis Murray at Columbia University. But Gabor Szegö told the Laxes that Richard Courant at New York University was very good at working with young people. Peter later said, "That was the best possible advice."

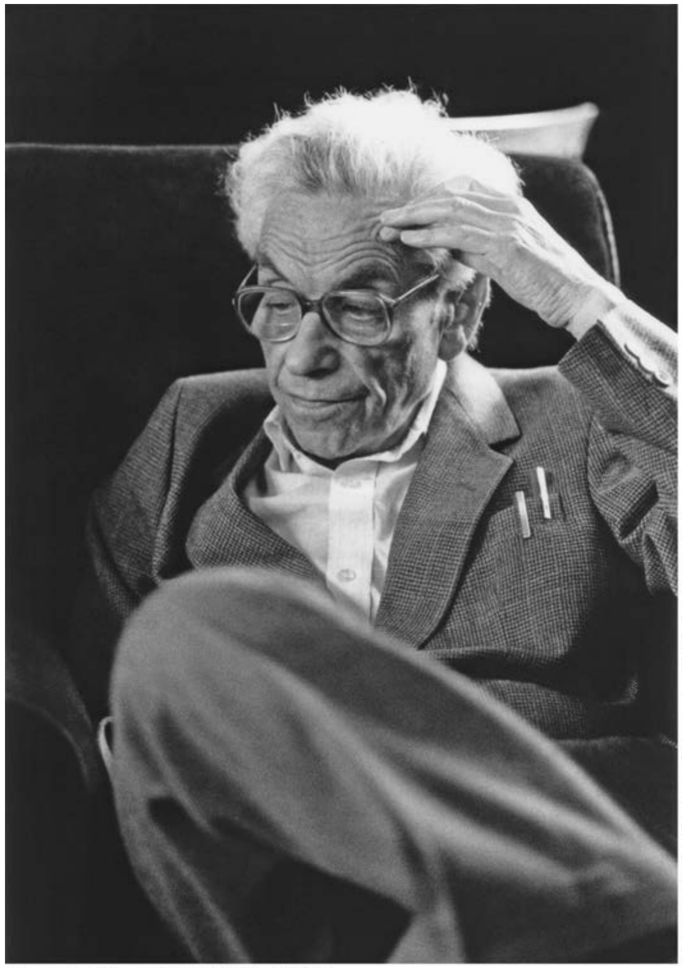
Courant as a Jew had been expelled from his leadership of the famous mathematical school at Göttingen in Germany and had been working hard for several years to build a great mathematical center at New York University. He greeted Peter warmly and welcomed him into his family in suburban New Rochelle. The Courants had two sons, Hans and Ernst, and two daughters, Gertrude and Leonore (Lori for short). Peter was already then an enthusiastic tennis player and amusing conversationalist.

Although classified as enemy aliens, "Within a month, my brother and I were in high school." Peter signed up at Stuyvesant High, a very selective science-oriented public school. He joined the math team, of course. "We won the City Championship that year. Somehow mathematics is the same everywhere. There were other students I could talk to about mathematics. Two of them, Marshall Rosenbluth and Rolf Landauer, became very successful physicists and members of the National Academy of Sciences."

While still in high school Peter was invited by Paul Erdős to visit the Institute for Advanced Study in Princeton. Erdős introduced him to Albert Einstein as a promising young Hungarian mathematician. Einstein said, "Why Hungarian?"

He didn't take any math courses at Stuyvesant; he was far beyond their math teachers. "I had to take English and American history, and I quickly fell in love with America." The history textbook was illustrated by contemporary humorous cartoons about U.S. politics, far from the stuffy way national history was taught in Hungary.

His main job was to learn English, so he took two English classes. Both were classes in English literature. In one of them, he had to read Hardy's novel *Return of the Native*. To this day he doesn't know why or to what the native returned. As



Paul Erdős, 1991 (1913-1996)

to the other literature class, he doesn't remember what they read. He passed his English courses with a C. He also had some more private tutoring in English.

Henrik and Klara enrolled Peter's older brother, John, in a well-recommended private high school. John got his high school diploma half a year later than his younger brother, Peter. John became a physicist. He lives in Washington, D.C., and has a literary bent, with a gift for translation. No doubt he bore a burden as the older brother of a famous prodigy. There is a certain parallel to the later strains and tensions between Peter's two sons. The older son, Johnny, was hyperactive, charismatic, and charming. Their younger son, Jimmy, struggled to defend himself against big brother's heavy teasing.

After graduating from Stuyvesant, Peter enrolled at New York University, where Richard Courant was making great progress in building his research and graduate program in mathematics. Undergraduate teaching was still mainly done by holdovers from the previous regime.

Dr. Lax opened an office in a fashionable neighborhood on the east side of Manhattan. For a few years the family lived on the East Side, and then in 1950 they settled into The Eldorado, a 31-story building on the West Side overlooking the lake in Central Park. (No one notices that the words "The" and "El" are redundant.) Their apartment was on the eleventh floor, facing the park. (It's now occupied by Peter's son, Dr. James Lax.) Two stories down, facing south, is the apartment where Peter and his wife, Anneli, would raise their sons.

The Eldorado is one of the Upper West Side's iconic architectural landmarks, filling the block front between West 90th and West 91st Streets. Its two majestic towers light up at night like giant candles. I have picked them out from the air as my plane approached LaGuardia Airport. The building is considered one of New York's finest art deco structures, with futuristic sculptural detailing and contrasting materials and textures. Among its tenants have been rabbi Stephen S. Wise, Barney Pressman (the owner of Barney's clothing store), Alec Baldwin, Faye Dunaway, Garrison Keillor, and Tuesday Weld. The novelist Sinclair Lewis lived in a tower apartment. In Herman Wouk's novel *Marjorie Morningstar*, The Eldorado is Marjorie Morningstar's address. A few blocks north are the Central Park tennis courts, twenty-five blocks away is Lincoln Center with the Metropolitan Opera, and NYU is a subway ride downtown. The family has had season tickets at the Met for many years.

The dining room in Peter's apartment has comfortable chairs at the table, about six side chairs against the walls, several large green plants in big pots, paintings on the walls, framed photographs on side tables, and a small balcony, where you look down at the interior courtyards of the block west of Central Park. In the living room there is plenty of space for the baby grand piano, and for bookshelves displaying works about art, literature, history, politics, and philosophy. There are large paintings on the walls and a small balcony looking out over West 90th Street. Of course there are also bedrooms, a kitchen, a pantry, and a maid's room.

Into the army

Peter Lax escaped from the European firestorm. However, the U.S. entered the war just as he arrived, and in 1944, after less than two years of college, he became eighteen, draft age. But he did not become cannon fodder in the U.S. wars against the Germans and the Japanese. After the unavoidable basic training (which he survived well, being in good physical shape) Peter was sent to school at Texas A&M. From there, after an interlude at Oak Ridge, he was shipped in June 1945 to the best possible place for him—a secret physics laboratory, where he would work alongside the world's greatest scientists, including John von Neumann.

Just how this came about Peter never knew for sure. He suspected the machinations of Richard Courant. "Courant had written Oswald Veblen to see what could be done about me. Because of his own experience in the trenches in the First World War, he was very concerned about the possible loss of talented young people."

Richard Courant was the man who provided the Mathematics Institute at Göttingen with a handsome new building, thanks to the Rockefeller Foundation. Later on it would be he who would make NYU's graduate math program the main mathematical support for the U.S. military. And a few years later, it would be he who would win a grant from the Sloan Foundation (aka General Motors) to build a 13-story headquarters for the Courant Institute. Who then but Richard Courant would have the know-how to induce the U.S. Army to pluck out a certain Private Peter D. Lax from among millions of trainees and assign said Private Lax to a certain unknown hilltop northwest of Santa Fe? Indeed, in the NYU archives I found copies of letters from Courant to influential mathematicians, trying to get Peter a good assignment while in the U.S. Army.

Peter writes, "I was first sent to a camp in Florida—an Infantry Replacement Training Center. A very ominous sounding description, the army didn't mince words. I was thin but very strong, I could handle a rifle, and I had no trouble on the marches. I got along with the people in my barracks. They were a cross-section, including some hillbillies, who I am sure found me as strange as I found them.

"I missed 'Village Fighting' (a regular part of basic training) because I was sent to ASTP, the Army Specialized Training Program. It was a program to take out of the ranks people who had some college education or had scored high on the army intelligence test. I was sent to Texas A&M (agricultural and mechanical) University in College Station, Texas, to learn some applied mathematics that might be useful to the military. Today it is a very good school, but then it was the butt of a lot of 'aggie' jokes. All male, no blacks, a very antiquated faculty, with some exceptions. Everybody in uniform. I passed the calculus test with flying colors, so I was excused from taking that course. One of the few research mathematicians on the faculty, Dr. Edmund Chester Klipple, offered to run an R. L. Moore-type seminar for me and another GI, Sol Weinstein, who also passed his calculus test with flying colors."

At that time every research mathematician at any southern university was a Moore student. Klipple's 1932 dissertation at the University of Texas was "Spaces in which there exist contiguous points".

"We proved theorems in real variables, some of them quite sophisticated. I learned quite a lot, for instance Euler's formula for the buckling of a column. This idyllic life came to an abrupt end when I received orders without further explanation to join 'the Manhattan project'; all I knew about it was that it wasn't in Manhattan." Peter had no idea that his family friend Leo Szilard, through a letter to Roosevelt signed jointly with Albert Einstein, had initiated a project to build an atomic bomb in the USA.

Manhattan Project. An army corporal among the Martians

"I got orders to go to Oak Ridge. Then one morning in Oak Ridge, about four weeks later, we are ordered to fall out and pile onto a train for an unknown destination."

("Fall out" is the army's command for "break out of your military formation, go individually to your next assignment.")

"After a couple of days we arrive at a place called Lamy, New Mexico," an insignificant location which, for obscure historical reasons, is the closest the Santa Fe Railroad gets to the city of Santa Fe.

Photograph by Nicholas Metropolis. Courtesy of the Los Alamos National Laboratory Archives

(L–R): John von Neumann, Richard Feynman and Stanislaw Ulam on picnic in Bandelier National Monument, New Mexico, 1949

“In Lamy we fall out again and pile into buses. We are driven to a small city. I recognized Santa Fe, for in 1942, our first summer in America, my parents, my brother, and I drove across America and passed through Santa Fe. From Santa Fe we are driven into the Jemez Mountains, into nowhere.

“It is then that I realize we are going to a secret project. We reach the secret site called Los Alamos.”

There Peter lived in a barracks, like any regular army soldier, along with other enlisted men who had been selected for Los Alamos. Some had done undergraduate work in physics or math, others were skilled machinists. While in the barracks they were subject to ordinary army discipline, including Saturday morning inspections.

“A few days after our arrival at Los Alamos we are told the task of the laboratory: to build a nuclear bomb whose explosive energy ‘e’ comes from Einstein’s $e = mc^2$. The bomb is built from plutonium, an element that does not exist in the universe, except for what we manufacture at a nuclear reactor at Hanford, Washington. We are also told that the energy from a nuclear reaction can be used not only for bombs but also to supply all the energy the world needs at very low cost. You can imagine the impact of these revelations. Partly because of that experience, I have never cared for science fiction. I had lived it.

“It was like a dream. The army didn’t have much power over us; it was the first time I was really on my own. There was the pleasure of being in a group working on a specific project. There was one goal, and I realized where mathematics fit into it.

“The secrecy of Los Alamos was secured partly through rigorous security rules, but also because the idea of atomic weapons was so unbelievable. However, one of my friends, the eccentric mathematician Paul Erdős, who had a very broad circle of friends and acquaintances, guessed what was going on. He wrote me a postcard:

‘A little birdie told me that you are working on atomic weapons.’

But since he wrote in Hungarian, he did not use the English idiom ‘a little birdie told me’, but rather its Hungarian equivalent: ‘My spies report to me’. Fortunately he sent the card to my home address, and my parents wisely did not forward it.

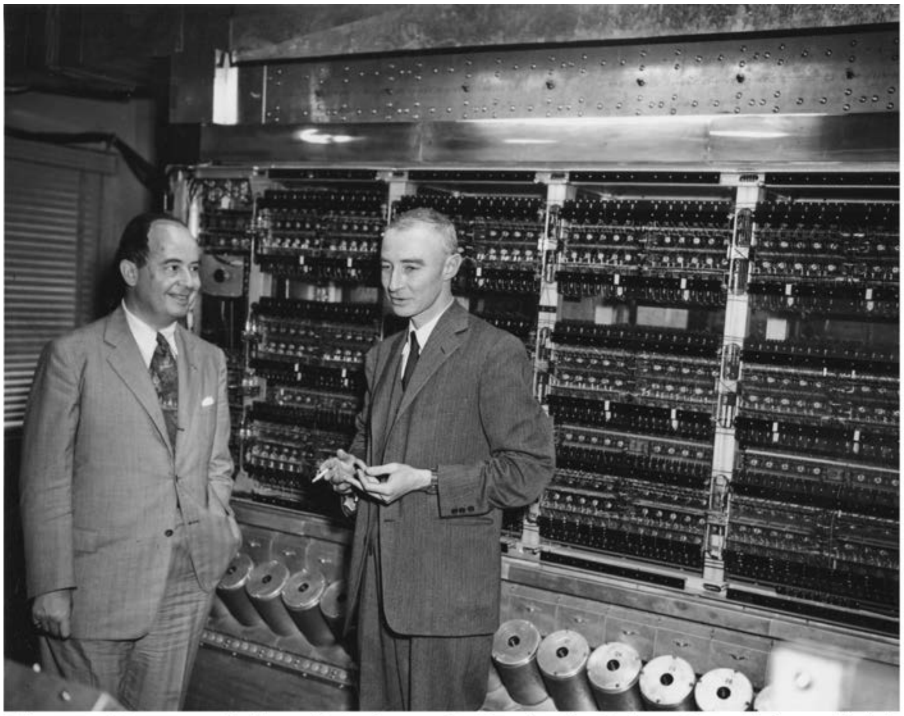
“Von Neumann was around a lot. He was a very important person already then, and extremely busy, but whenever he came he would give a lecture. At that time he talked about game theory and computers. He was very much convinced that the task at Los Alamos would turn toward computing, since they would be unable to fulfill their mission without it.

“No mere list of von Neumann’s achievements gives a proper picture of the man; for those who are too young to have glimpsed him I offer the image of Gelfand and Michael Atiyah rolled into one, with a couple of physicists and economists added for good measure. He carried thinking further than most people can conceive of its being carried. That is the reason he was so much sought after by the government for advice. Not only the government but many mathematicians sought von Neumann’s advice about their research. Not that von Neumann was able to solve a difficult problem in a single interview, but he had an uncanny ability of relating it to other problems. Often such a reformulation represented the labor of six months of the person who posed the question.

“Richard Feynman was also there. Although he was quite young, he was already legendary. I had just turned nineteen, so my interaction was more with young mathematicians like Richard Bellman, John Kemeny, Alex Heller, and Paul Olum. We became friends, friendships that lasted a lifetime. I also saw a lot of Stan Ulam.”

These young mathematicians, and Peter himself, had been picked by an army program specially designed to detect and utilize such “brainiacs”. “An important supplement to the prestigious scientists who were recruited were the draftees of the MED’s (Manhattan Engineering District’s) Special Engineer Detachment (SED). The SED was composed of mostly young scientists, engineers, and technicians who had been drafted into the army. Rather than being sent off to combat, they were transferred to Los Alamos, or elsewhere, to fill a personnel shortage and perform a variety of scientific and technical tasks. Almost 30 percent of them had college degrees. Many had been in graduate school when they were called, and some had completed their Ph.D’s. By the end of 1943 nearly 475 SED’s had arrived; by 1945 the unit included 1,823 men.” (*Racing for the Bomb*, Robert S. Norris, Steerforth Press, South Royalton, Vermont, 2002, page 247.)

Peter writes that “some of the leading scientists, Oppenheimer, Bethe, Kistiakowski, Teller, and others were the leaders of the Project. World famous scientists like Fermi, von Neumann and others were frequent consultants. I wondered how come that I was chosen for this project. I surmised, and still believe, that Courant had recommended me.”



Alan Richards, photographer. From the Shelby White and Leon Levy Archives Center, Institute for Advanced Study, Princeton, NJ

John von Neumann (left) and Manhattan Project leader Robert Oppenheimer (right) in front of Princeton's Institute for Advanced Study computer, 1952

Courtesy of Peter Lax

Niels Bohr (left) and Richard Courant (right)

Hiking and cross-country skiing were great weekend pastimes. He has a photo (shown here) of himself seated on a mountaintop near Enrico Fermi, the leading physicist of the Manhattan Project. He even played tennis with Fermi. He thinks he won. The memory still makes him smile. He tried to learn to fly an airplane. At age eighteen, while still an army private, he published his first paper, the proof of a conjecture he had heard from Paul Erdős, "On the derivative of a polynomial," in the *Bulletin of the American Mathematical Society.*

"I was placed in T (for Theory) Division. There was no special mathematics group, perhaps because the leading mathematician at Los Alamos, Stan Ulam, was not inclined to do administrative work. So mathematicians were assigned to work with physicists; that way we learned how a mathematician can help solve a scientific problem.

"At first I was asked to do calculations with a Marchant, a hand-operated electric calculating machine, but very soon I graduated from that. I knew very little physics then. I still wish I knew more. I was assigned to work on neutron distribution in general, neutron transport problems. The fanciest piece of work I did was a calculation of the criticality of an ellipsoid. The theory of neutron transport is a linear theory. Many years later I heard the distinguished French physicist Robert Dautray, who was one of the leaders of the French nuclear development, remark that since nuclear fission is governed by linear laws, it is possible to scale up experiments. Nuclear fusion, in contrast, is governed by a nonlinear theory, so it is not possible to scale up experiments. This is one of the difficulties that makes it so hard to generate energy by nuclear fusion."

This assignment at Los Alamos—to calculate the critical size of an ellipsoid, as a generalization of a sphere—was a rather classical bit of applied mathematics. The ellipsoid in question would be composed of "fissionable material"—uranium 235 or plutonium. "Critical size" means the size needed in order to sustain a chain reaction. A sufficiently eccentric ellipsoid might serve to represent a cylinder. One of the bombs that would be dropped on Japan was cylindrical in shape.

The prominence of four brilliant Hungarians in the Manhattan Project (Eugene Wigner and Leo Szilard at Argonne Laboratory in Illinois, and John von Neumann and Edward Teller in Los Alamos) resulted in the following story: "Oppenheimer managed to secretly recruit four extraterrestrials for his lab, but they could be recognized by their weird English accents. As a coverup, they all claimed to be Hungarian."

To tell the truth, Peter Lax has never completely lost the last vestige of his Hungarian accent.

At the top of the list, in terms of sheer brain power, was John von Neumann. "He had interviewed me in New York soon after we arrived. After we met again at Los Alamos, he was always available, even though he was already a very important person and extremely busy. When I latched on to some of his contributions, like the von Neumann criterion for stability and shock capturing, he was interested in my ideas, and I profited from his ideas." (More on this in Chapter 10.)

Peter has written a short biography of von Neumann, which I include as Appendix 2, both to present the story of his life and accomplishments and to convey the tremendous admiration for von Neumann that Peter has felt all his life. The last

Courtesy of Gerald L. Alexanderson, from *Pólya Picture Album: Encounters in Mathematics*

Gabor Szegő and George Pólya, Berlin, 1925

few paragraphs describe von Neumann's foresight about computing and his seminal work on shock waves and the approximate solution of partial differential equations. Peter could have added, "and much of my own work has been a continuation and development of von Neumann's beginnings in these areas."

Among mathematicians, Peter has a great reputation as a storyteller. He has many stories about the young mathematicians he met as a nineteen-year-old army private at Los Alamos.

"Dick Bellman was somewhat older than the rest of us; he was already married. His wife moved to an apartment in Albuquerque to be near Dick. The expense proved too great, so she joined the WACs (Woman's Army Corps). Dick sublet the apartment to a fellow soldier named Greenglass, who a few years later in 1950 became infamous as an atomic spy, brother-in-law of the Rosenbergs. The transmission of atomic secrets took place in the apartment that Greenglass had leased from Bellman. By this time Bellman was consultant to the Rand Corporation on a classified project requiring secret clearance. The connection with Greenglass caused

Courtesy of Peter Lax

Peter (left) and Enrico Fermi (right) on a hike in the mountains around Los Alamos with a colleague

the suspension of his clearance pending a security hearing. I was able to testify that far from being a friend, Dick loathed Greenglass. His clearance was restored.

"Many years later Bellman was felled by a brain tumor; it was not malignant but caused extensive damage, including to muscles of his face. Dick said that it made him look like a Picasso portrait. He didn't think he had lost any intellectual brain function, 'but if I did,' he said, 'I could afford it.'

"John Kemeny was another of the prodigies who made it to Los Alamos. He was a brilliant student at Princeton when he was drafted, and captain of the debating team in his freshman year. He came to the U.S. with his family from Hungary a couple of years before I came, and after being drafted received U.S, citizenship, as did I. He wrote his parents how pleased he was to have this honor bestowed on him so soon and without being asked any stupid question about being a communist. All mail in and out of Los Alamos was censored, so the remark about being a communist was picked up, and John was summoned by the base Security Officer. His friends were waiting anxiously in the lobby of the security office while the interrogation took place. After about two and a half hours John emerges. 'What happened?' we asked. 'I made the Security Officer admit that there are several things wrong with the capitalistic system,' John said."

Kemeny has provided a vivid description of computing as it was done in the Manhattan Project, with von Neumann's response. (*Man and the Computer*, quoted on page 275 of Marx.)

"In Los Alamos each of our machines was designed to carry out one or two arithmetical operations, for example $A \times B + C$. The values of A, B and C were fed to the computer by a deck of IBM cards, and the computer performed the same operation on each card. The new deck was then moved manually to the next calculating machine, which carried the calculation one step further. The control of the machine was by means of a plug-board, which had to be specially rewired for each type of operation. Neumann argued that those machines, which depended heavily on mechanical parts, were much too slow to be useful. Therefore he proposed an entirely electronic device. He went on to argue that while the decimal system was perfectly practical for mechanical devices, a binary system would be much easier to implement electronically because of the efficiency of an on-off system. Next he pointed out that if we had faster machines it did not make sense for human beings to have to interfere at each step. Therefore he advocated the existence of an internal memory in which partial results could be retained so that the computer could automatically go through many rounds of operations."

Kemeny became chairman at Dartmouth, where he developed the computer language BASIC and computerized the campus. He wrote a seminal introductory text, *Finite Mathematics*, with Snell and Thompson. He was chosen to be president of Dartmouth. During a ten-year tenure he accomplished a lot, against much opposition by alumni: the admission of women and many reforms of the curriculum. He told Peter that when the trustees offered him the presidency, they warned him that "this is a 100% job, that he should forget about his former interests." John told them that he realized that, but relaxing is important too, such as playing golf. Would the trustees mind if twice a week he took off a couple of hours. Not at all, they told him. "Actually I don't play golf," said John, "but I would like to teach a math class."

Stan Ulam, one of the originators of the so-called Monte Carlo method of calculation, was one of von Neumann's closest friends; that is how he came to be at Los Alamos. Peter says that Ulam was a most unusual mathematician: "He worked with ideas, not with equations or formulas. He had an original sense of humor; when after the war Los Alamos was somewhat opened up to the outside world, the Catholic community installed a prefabricated church in town. Stan dubbed it 'Santa Maria della Bomba'."

Even Niels Bohr visited once; since he was so closely associated with nuclear physics, the security people insisted that he use an alias, Nicolas Baker. (Enrico Fermi's alias was Henry Farmer.) At a party in the evening one of the guests who had been to Copenhagen in the years before the war recognized Bohr and said, "Professor Bohr, how nice to see you here."

Bohr, remembering the drilling by the security people, replied,"No, I am Nicolas Baker." But then he added, "But you are Mrs. Hautermans."

"No", she replied, "I am Mrs. Placzek." (She had divorced and remarried.)

When asked about the Hungarian physicist Edward Teller, Peter replied, "Well, of course blood is thicker than water, even heavy water, so we were friends." (They were both graduates of the same gymnasium, the *Minta*.) Teller later became "the father of the H-bomb" and also the principal advocate of the "Star Wars" project of antiballistic missile defense against a possible nuclear attack, which was embraced by President Ronald Reagan despite the nearly unanimous judgment among competent experts that it was a dangerous delusion. Teller also led in labeling Robert Oppenheimer, the main leader of the Manhattan Project, as a "security risk."

But all that happened later on. To Peter as an army corporal far from home, Teller was a welcome familiar face.

At the time, nearly everyone involved with the atomic arms race was deeply worried that the Germans would beat us to it. They had Werner Heisenberg and a whole crew of other world-class physicists. In fact, during the war Heisenberg came from Germany to visit Bohr in Denmark, hoping to learn in conversation with Bohr whether the U.S. was working on an atom bomb. He didn't learn any such thing. But as a result of this visit, Bohr did realize that Germany was indeed working on it.

The physicist Frank Hoyt, one of Peter's supervisors at Los Alamos, was charged with scrutinizing all publications of Heisenberg to see if they were a by-product of work on atomic weapons. Hoyt concluded that Heisenberg's basic paper on scattering theory, published in 1943, had nothing to do with nuclear weapons. On May 8, 1945, Germany surrendered. It became clear that despite their head start they had never come close to making an atom bomb. Werner Heisenberg claimed that he had slowed down the project. Niels Bohr doubted this.

Two types of atom bomb were being built: one with uranium 235 and one with plutonium. The uranium bomb was relatively simple; there was no necessity for a test. The plutonium bomb was more complex, so one was set aside for testing. Six weeks after Peter arrived at Los Alamos, on July 16, 1945, the plutonium bomb was tested at a remote desert site called "Trinity" in the Alamogordo Bombing and Gunnery Range.

A little after midnight, the physicist Donald Hornig climbed down from the tower where the bomb was placed and went to a bunker five miles away, where he joined Robert Oppenheimer and others who were waiting to see if the "the gadget", as they called it, would actually go off. Hornig took his next assigned position: keeping his finger on a control switch to abort the blast if something should go awry. Unexpected thunderstorms delayed the experiment. But the weather cleared up, and at 5:29 a.m. the bomb exploded. Hornig later said that the swirling orange fireball filling the sky was "one of the most aesthetically beautiful things I have ever seen." (See the photo following this chapter.) The explosion was much stronger than the physicists expected; some of their measuring instruments were destroyed by the blast. In the following days, Peter witnessed "the frantic effort of scientists to calculate the effect of the explosion, and their efforts after the test to reconcile the measured values with their calculations."

With Nazi Germany defeated, the original impetus that had led Leo Szilard and Albert Einstein to urge the bomb on Franklin D. Roosevelt no longer existed. The war against Japan was continuing. Many of the physicists who had worked on the bomb were opposed to dropping it on Japanese civilians. Szilard circulated a petition urging a demonstration of the bomb on some uninhabited place to give Japan a chance to surrender without suffering an atomic explosion. Lewis Strauss, an influential banker and admiral, likewise opposed dropping the bomb on a Japanese city without first providing a demonstration of its power.

Peter Lax, like other enlisted men in danger of being sent to invade Japan, was in favor of using the bomb. "I was in the army, and all of us in the army expected to be sent to the Pacific to participate in the invasion of Japan. You remember the tremendous slaughter that the invasion of Normandy brought about. That would have been nothing compared to the invasion of the Japanese mainland. You remember the tremendous slaughter on Okinawa and Iwo Jima. The Japanese would have resisted to the last man. The atomic bomb put an end to all this and made an invasion unnecessary. I don't believe revisionist historians who say: 'Oh, Japan was already beaten, they would have surrendered anyway.' I don't see any evidence for that."

He raises another point. "Would the world have had the horror of nuclear war if it had not seen what one bomb could do? The world was inoculated against using nuclear weaponry by its use. I am not saying that alone justifies it, and it certainly was not the justification for its use. But I think that is a historical fact."

The generals running the Manhattan Project and President Harry Truman had little respect for people with qualms about the bomb. In Truman's inner circle, failure to use every available weapon against Japan would have been considered politically fatal. Calculation about a presidential election would have trumped any other consideration.

Peter writes that "members of the team that was sent to the Pacific to help arm the bomb received an inoculation against yellow fever, which causes a somewhat painful swelling of the arm. Since their mission was top secret, they were sternly warned not to cry out if someone accidentally bumped into their arm.

"When the uranium bomb was delivered to the air force base in the Pacific to be dropped on Hiroshima, scientists from Los Alamos explained to the commanding officer, General LeMay, the basic principles of nuclear fission. 'How many times have you tested this bomb?' LeMay demanded to know. The bomb measured only 28 inches by 120 inches. When told that it had never been tested, he laughed out loud and regarded his visitors as irresponsible eccentrics."

At 8:15 a.m. August 6, 1945, at an altitude over Hiroshima chosen to be optimal for maximal effectiveness, a calculation credited to John von Neumann in his U.S. government award for military service, "there was a blinding flash in the sky, and a great rush of air, and a rumble of noise extending for many miles" (Official U.S. government report of the Manhattan Project Atomic Bomb Investigating Group).

Around 50,000 died immediately, mostly "noncombatants"—women, children, and men too old for military service. As many as 166,000 more perished within four months because of the bomb. Others died later from cancers induced by nuclear radiation.

The emperor of Japan consulted with his generals about this new American weapon. The Soviet Union was joining the war against Japan, massive numbers of Russian troops were moving from the European front to the Pacific. To hasten the Japanese surrender, the U.S. dropped another atom bomb on August 9, this one over Nagasaki; 60,000 to 80,000 more "noncombatants" were killed instantly. Japan surrendered on August 15.

The explosions at Trinity, Hiroshima, and Nagasaki all took place before Peter had completed his analysis of an ellipsoidal bomb. As usually happens to such research, his report was first "classified" and then appropriately filed away.

Leo Szilard was the most active of many physicists who were deeply frightened of an atomic arms race. The U.S. had a monopoly on the bomb at first and tried hard to keep its manufacture a "secret", but scientists knew that in a few years Russia would have the bomb too. It turned out that the German refugee physicist Klaus Fuchs and others had already made Stalin aware of the Manhattan Project. The only secret was whether the bomb would work, and Hiroshima ended that secrecy.

A serious effort was made to achieve international control of atomic weapons through a United Nations agency. The Baruch Plan would have required both the U.S. and the U.S.S.R. to open up their secret atomic research to an international agency. The Soviets refused first.

The next big struggle was to take the atom bomb away from the U.S. Army and put it under civilian control. This effort was successful; the Atomic Energy Commission was created. John von Neumann became a commissioner.

Most of the leading physicists at Los Alamos quickly dispersed back to regular campus life. But a history-making laboratory such as Los Alamos could hardly be disbanded or destroyed. There remained plenty of interesting scientific research about this new physical phenomenon, the atom bomb. (Not to mention practical military questions: making more efficient, more convenient, more versatile bombs.) Los Alamos became a permanent site for science and engineering related to atom bombs, and two more such laboratories were created in Albuquerque, New Mexico, and Livermore, California. At Livermore, near Berkeley, Edward Teller had free rein to try to build his "Super", which had been opposed at the Manhattan Project by Robert Oppenheimer. Ironically, the ultimate success of the H-bomb was made possible by an insight contributed by the Los Alamos mathematician Stan Ulam.

There was a succession of atomic explosions, as various nations announced their entrance into the atomic club. On March 1, 1954, at Bikini, the U.S. performed a successful test of a hydrogen bomb. There is now an international agreement not to test atom bombs in the atmosphere, but underground testing is still permitted.

For several years after the war, Peter Lax and John von Neumann were visiting consultants at Los Alamos. Sandia National Laboratory has long been the major employer in Albuquerque, New Mexico, where I taught mathematics at the University of New Mexico. Between Sandia and Los Alamos, the atomic industry is a major source of federal dollars for New Mexico. Our senators and congress-persons, in bipartisan fashion, reliably and earnestly support its appropriations.

Szilard worked persistently to prevent a nuclear holocaust. In 1962 he helped to found the Council for a Livable World. The council's goal is to warn the public and congress of the threat of nuclear war and encourage rational arms control and nuclear disarmament. As the first physicist to envision a chain reaction and as the initiator of the U.S. effort to build an atom bomb, Szilard may have felt a special sense of personal responsibility for avoiding a nuclear catastrophe. While Peter was in Los Alamos, Szilard was working with Fermi at the Chicago branch of the Manhattan Project.

Asked by an interviewer who was his favorite among the so-called "Martians", the great Hungarian scientists who worked in the Manhattan Project, Peter answered, "Szilard had perhaps the most fantastic imagination. He could see the future and act on it. Very few people foresee the future and those who do don't do anything. But he did. Perhaps he was the most remarkable among them." The following story illustrates Szilard's foresight: The day after Hitler came to power, he withdrew his money from the German bank and left the country.

The physicists at Los Alamos, who had been kept from academic work, organized a Los Alamos branch of the University of New Mexico. Peter took some courses and was assistant in a course on mechanics given by Chaim Richman. "I wrote up the notes. I didn't know too much, but I was learning. The army still needed us at Los Alamos, so they made a deal. They agreed to discharge us if we agreed to stay on as civilians until the following May. It was a very good deal." Peter was discharged from the army with the rank of corporal.

In the summer of 1946 he went from New Mexico to California and spent another summer semester at Stanford with the Szegös. He writes, "This time I took some reading courses with George Pólya. Pólya's older brother was a good friend of my father's. He was a very prominent surgeon, very skillful and very innovative. In fact, George Pólya was known in Budapest as the talented kid brother of the famous surgeon Jenö Sándor Pólya." (Jenö Pólya is still remembered for the "Reichel-Pólya operation", a type of posterior gastroenterostomy. Between World War I and World War II, American surgeons came to Budapest to observe his surgical technique, and in 1939 he was elected an honorary member of the American College of Surgeons. Jenö Pólya was murdered by the Nazis during the Siege of Budapest. His body was never found.)

In Peter's article "The bomb, Sputnik, computers, and European mathematicians", he wrote, "It was under the leadership of Szegö that Stanford established itself as one of the foremost schools of analysis and statistics."

After getting his Ph.D., Peter returned to Los Alamos in 1949 as a staff member for a year. He writes, "By that time von Neumann had started to spend a lot of time there. The focus of his interest was numerical schemes. We didn't have a computer yet, but already during the war von Neumann realized that to do bomb calculations, analytical methods were useless; one needed massive computing. He also realized that computing is good not just for bomb-making but for solving any large-scale scientific or engineering problem. And he also realized that it's useful above all to explore which way science should be developed. As he said, 'It gives us those hints without which any progress is unattainable, what the phenomena are that we are looking for.' "

Peter coined a capsule summary of that insight:
Computing is the tool for the theorist, used in the manner of the experimentalist.

The fundamental mathematical-physical problem for theorists at Los Alamos and in laboratories around the world is a classical one inherited from the nineteenth-century: compressible flow. When studied from the viewpoint of heavier-than-air flight, it is known as "aerodynamics". When studied with interest in the earth's atmosphere on a large scale, it is known as "meteorology". When it is complicated by strong effects of electromagnetism, as in the interior of stars, it becomes "astrophysics". In attempts to create energy by nuclear fusion or in studies of the details of a nuclear or thermonuclear explosion, it is called "magnetohydrodynamics" or "plasma physics". It is "classical" or "old-fashioned" in the sense that the physics is primarily continuum mechanics, not quantum mechanics or relativity. The mathematics doesn't require "modern" innovations such as abstract algebra or algebraic topology or category theory. The governing equations would be understandable to Euler or Maxwell. But it still frustrates and puzzles the most powerful living mathematical minds. While the shocks—discontinuities in finite time—are a prominent phenomenon of *compressible* flow (aerodynamics), it is unknown to this day whether blowup in finite time is possible in the better-behaved case of *incompressible* flow (such as water waves). The Clay Foundation is offering $1,000,000 for a rigorous solution to that question.

These equations absolutely require high-speed computer simulation to go where pure analysis cannot penetrate. How to keep track of the shocks that can arise from a smooth initial state? This has been a continuing theme of Peter Lax's research. We discuss this work in more detail in Chapter 10. "When I got back to Los Alamos in 1949 there was a great deal of research on difference schemes for partial differential equations. But it wasn't until 1952 that von Neumann's machine, the JOHNIAC or MANIAC, was built. Then versions of it were built simultaneously in many places: at the Institute for Advanced Study in Princeton, at Argonne Lab in Illinois, and at Los Alamos, where Nicholas C. Metropolis and James Richardson were most deeply involved. That was when I started my experiments on shock capturing. I remember writing machine code for the MANIAC." "Experiments" here means "computer experiments", "numerical experiments". To study shocks "experimentally", the mathematician starts out with the differential equations for compressible flow. Since the computer works only with discrete information, he "discretizes" the system of differential equations, replacing the differentials or derivatives by finite differences. This first step is far from routine! It takes mathematical finesse to make an approximation which is amenable to computation and also reasonably true to the continuous flow it is supposed to approximate. Shocks can develop spontaneously, even if the original state was smooth. And it isn't easy to know where and when the shocks may arise! Then it is complicated to follow them as they move and evolve. "Shock capturing" was the method proposed by von Neumann. One uses some mathematical device to smooth out the flow, replacing discontinuities with regions of rapid transition, which are much easier to work with. By numerical experiments, von Neumann and Lax familiarized themselves with shock flows. This prepared them to devise effective computational algorithms and even rigorous proofs. Peter came back to Los Alamos every summer after that. He recalls, "Each summer there was a brand new machine which made last year's model primitive. Of course all these machines were incredibly primitive by our standards, but they could do more and more and more." During an interview, the mathematician Phil Colella seemed amazed that Peter Lax had actually written computer programs in "machine language" in the days before compilers and executive programs existed. *Colella*: So you were experimenting with shock capturing at Los Alamos in the late 1940s—well, I guess when the first computer arrived.

Lax: Yes.

Colella: You actually got in there and programmed these naked machines.

Lax: I actually programmed, yes. Later on I used assembly language, but still pre-FORTRAN.

Colella: What was the environment like there just after the war?

Lax: I would say ideal. The military realized that they had blundered by doubting the importance of science, and they decided never again to expose themselves to such danger. Their respect for science grew enormously, enormous resources were put at the disposal of scientists, and they were wise enough to see that they didn't always have to be devoted to a specific task; general research also had to be supported. That spirit still lives on, although not nearly to the same extent. "The time I spent in Los Alamos, especially the later exposure, shaped my mathematical thinking. First of all, it was the experience of being part of a scientific team—not just of mathematicians, but people with different outlooks—with the aim being not a theorem but a product. One cannot learn that from books; one must be a participant. For that reason I urged my students to spend at least a summer as a visitor at Los Alamos. Secondly, it was there, in the 1950s, that I became imbued with the utter importance of computing for science and mathematics. Under the influence of von Neumann, for a while in the 1950s and the early 1960s, Los Alamos was the undisputed leader in computational science."

NYU and the Courant Institute

In the fall of 1946 Peter went back to NYU, first as an undergraduate, then as a graduate student. The math program had just moved into the Bible House on Astor Place near Cooper Union. Back in 1853 the American Bible Society had relocated there from a modest headquarters on Nassau Street. The new grand and fashionable 5-story cast-iron structure was an architectural and technological marvel, occupying a full city block. It was financed by the richest Christians in New York, and it made the American Bible Society one of the most powerful reform organizations in the nation. Thousands of Christian tourists visited every year, and Mark Twain said after a visit to the Bible House, "I enjoyed the time more than I could possibly have done in any circus." The Bible House was primarily a publishing facility, and it produced tens of millions of bibles in many languages. It helped bring publishers, libraries, and bookstores to the Cooper Square-4th Avenue neighborhood. Its demolition in 1956 marked the beginning of the end of "book row".

From the *New York Times* (April 2, 1956)

1853 BIBLE HOUSE TO BE DEMOLISHED

Wreckers Start Work Today on City's First Building with Iron Framework

As a graduate student at NYU Peter found outstanding teachers, including Richard Courant, Kurt Friedrichs, and Fritz John, and outstanding fellow students, including Joe Keller, Cathleen Morawetz, Harold Grad, Louis Nirenberg, Martin Kruskal, and Anneli Cahn, soon to become Anneli Lax. Keller became a professor at NYU and then at Stanford, and the leader of a very prolific school of applied mathematics, especially known for his method of calculating diffraction of light rays from edges, corners, and cusps of reflecting obstacles. Grad became the key leader at NYU of a long-continuing group effort to understand hydromagnetic flows, or "plasmas". Controlling these is the key to generating electric power from nuclear fusion, the source of the sun's power. Kruskal became famous for an original way to represent relativistic mechanics and then later on for his role in relating the Korteweg-de Vries partial differential equation (the "soliton" equation) to the Fermi-Pasta-Ulam phenomenon (recurrence in a flow which was expected to be ergodic). Nirenberg, from Montreal, became Peter's lifelong closest friend and also, like Peter, a preeminent world leader in his own particular branch of mathematics, elliptic partial differential equations, which can describe equilibrium situations in elasticity, fluid flow, or electromagnetism.

Peter received his Ph.D. in 1949 for a thesis, "Nonlinear system of hyperbolic partial differential equations in two independent variables", written under Courant's student Kurt Otto Friedrichs. Partial differential equations (PDE) would be Peter's lifelong mathematical milieu. According to the Mathematics Genealogy Project, Peter by now has had 55 doctoral students and 518 doctoral descendents.