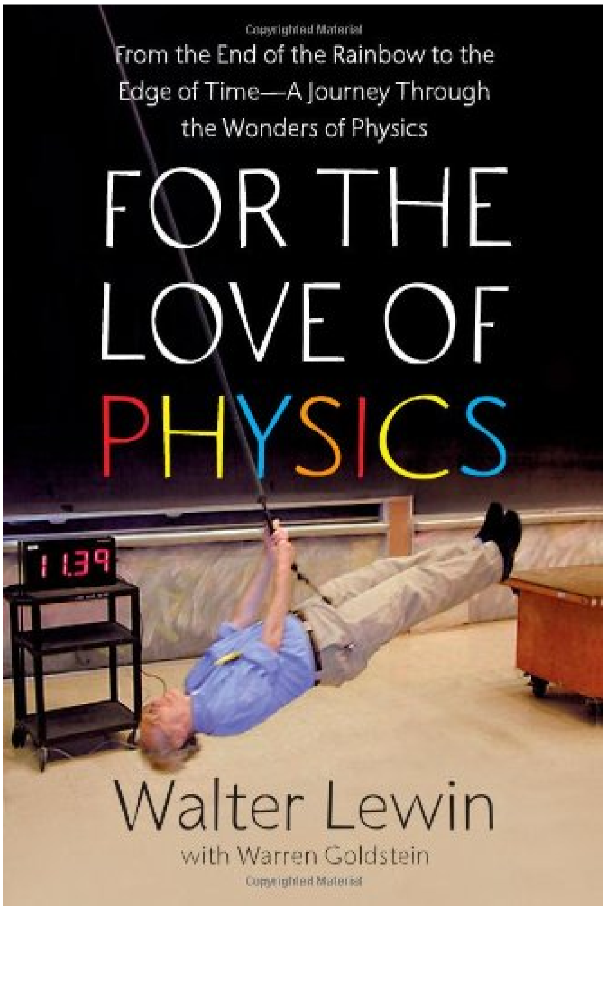
FOR THE LOVE OF PHYSICS: FROM THE END OF THE RAINBOW TO THE EDGE OF TIME - A JOURNEY THROUGH THE WONDERS OF PHYSICS BY WALTER LEWIN



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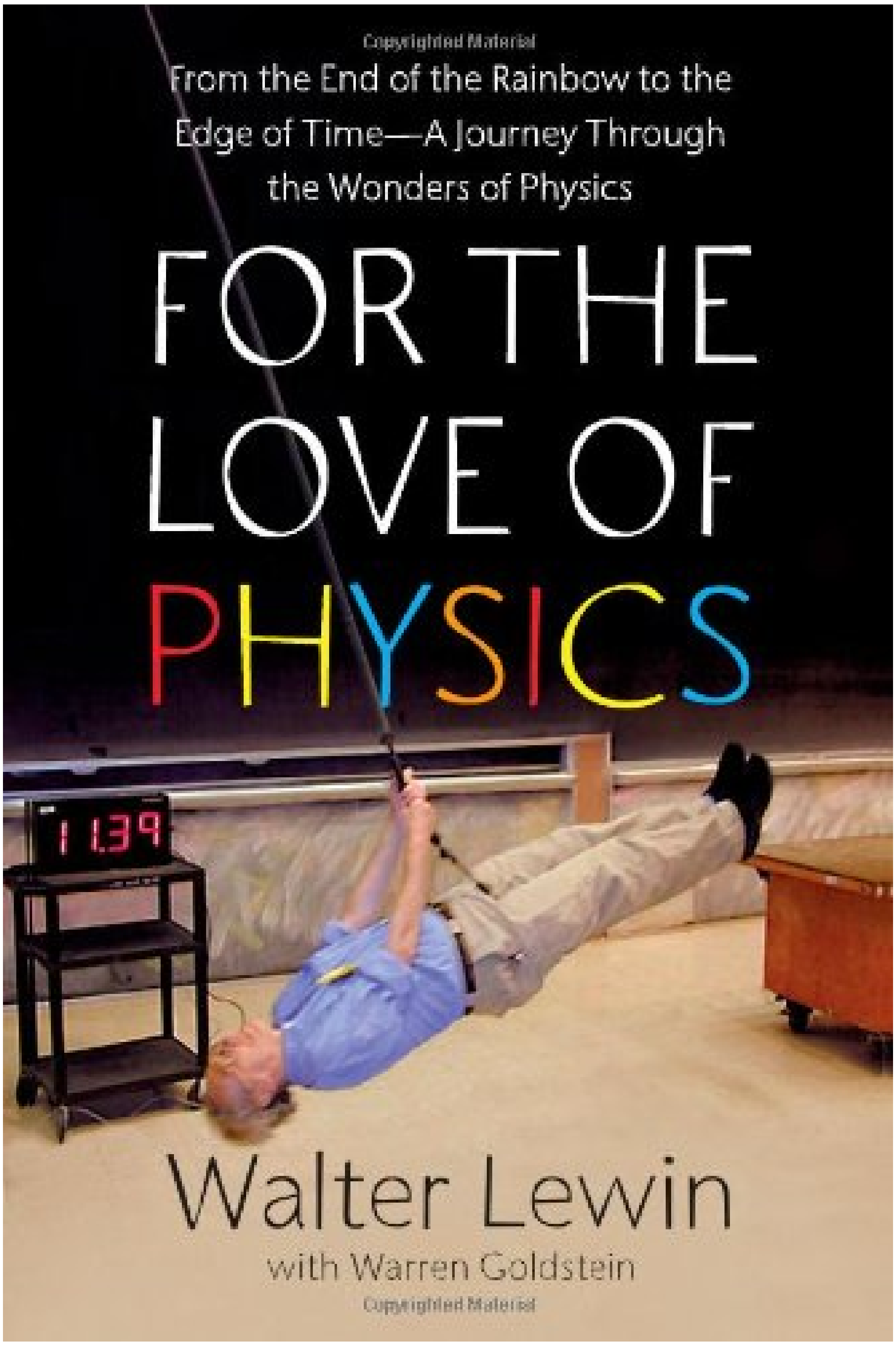
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From the End of the Rainbow to the
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When some people taking a look at you while reviewing *For The Love Of Physics: From The End Of The Rainbow To The Edge Of Time - A Journey Through The Wonders Of Physics By Walter Lewin*, you could feel so honored. But, as opposed to other people feels you must instil in yourself that you are reading For The Love Of Physics: From The End Of The Rainbow To The Edge Of Time - A Journey Through The Wonders Of Physics By Walter Lewin not as a result of that reasons. Reading this For The Love Of Physics: From The End Of The Rainbow To The Edge Of Time - A Journey Through The Wonders Of Physics By Walter Lewin will provide you greater than individuals admire. It will certainly guide to recognize more than the people staring at you. Already, there are lots of sources to discovering, checking out a book For The Love Of Physics: From The End Of The Rainbow To The Edge Of Time - A Journey Through The Wonders Of Physics By Walter Lewin still comes to be the front runner as a great way.

Review
"MIT's Lewin is deservedly popular for his memorable physics lectures (both live and on MIT's Open Course Web site and YouTube), and this quick-paced autobiography-cum-physics intro fully captures his candor and lively teaching style...joyful...[this text] glows with energy and should please a wide range of readers."--"Publishers Weekly" (starred review)

About the Author
Walter Lewin taught the three core classes in physics at MIT for more than thirty years and made major discoveries in the area of X-ray astronomy. His physics lectures have been the subject of great acclaim, including a 60 Minutes feature, stories in the New York Times, Washington Post, Boston Globe, Newsweek and US News and World Report. They have also been top draws on YouTube and iTunes University. He was awarded three prizes for excellence in undergraduate teaching. He has published more than 450 scientific articles, and his honors and awards include the NASA Award for Exceptional Scientific Achievement, the Alexander von Humboldt Award, and a Guggenheim Fellowship. He became a corresponding member of the Royal Netherlands Academy of Arts and Sciences and Fellow of the American Physical Society in 1993. He lives in Cambridge, Massachusetts.

Warren Goldstein is a professor of history and chair of the History Department at the University of Hartford. A prizewinning historian, essayist, and journalist, he has had a lifelong fascination with physics. His writing has appeared in the New York Times, Washington Post, Boston Globe, Chicago Tribune and many other national periodicals. His prior books include Playing for Keeps: A History of Early Baseball and William Sloane Coffin, Jr.: A Holy Impatience.

For the Love of Physics CHAPTER 1

From the Nucleus to Deep Space

It's amazing, really. My mother's father was illiterate, a custodian. Two generations later I'm a full professor at MIT. I owe a lot to the Dutch educational system. I went to graduate school at the Delft University of Technology in the Netherlands, and killed three birds with one stone.

Right from the start, I began teaching physics. To pay for school I had to take out a loan from the Dutch government, and if I taught full time, at least twenty hours a week, each year the government would forgive one-fifth of my loan. Another advantage of teaching was that I wouldn't have to serve in the army. The military would have been the worst, an absolute disaster for me. I'm allergic to all forms of authority—it's just in my personality—and I knew I would have ended up mouthing off and scrubbing floors. So I taught math and physics full time, twenty-two contact hours per week, at the Libanon Lyceum in Rotterdam, to sixteen-and seventeen-year-olds. I avoided the army, did not have to pay back my loan, and was getting my PhD, all at the same time.

I also learned to teach. For me, teaching high school students, being able to change the minds of young people in a positive way, that was thrilling. I always tried to make classes interesting but also fun for the students, even though the school itself was quite strict. The classroom doors had transom windows at the top, and one of the headmasters would sometimes climb up on a chair and spy on teachers through the transom. Can you believe it?

I wasn't caught up in the school culture, and being in graduate school, I was boiling over with enthusiasm. My goal was to impart that enthusiasm to my students, to help them see the beauty of the world all around them in a new way, to change them so that they would see the world of physics as beautiful, and would understand that physics is everywhere, that it permeates our lives. What counts, I found, is not what you cover, but what you uncover. Covering subjects in a class can be a boring exercise, and students feel it. Uncovering the laws of physics and making them see through the equations, on the other hand, demonstrates the process of discovery, with all its newness and excitement, and students love being part of it.

I got to do this also in a different way far outside the classroom. Every year the school sponsored a week-long vacation when a teacher would take the kids on a trip to a fairly remote and primitive campsite. My wife, Huibertha, and I did it once and loved it. We all cooked together and slept in tents. Then, since we were so far from city lights, we woke all the kids up in the middle of one night, gave them hot chocolate, and took them out to look at the stars. We identified constellations and planets and they got to see the Milky Way in its full glory.

I wasn't studying or even teaching astrophysics—in fact, I was designing experiments to detect some of the smallest particles in the universe—but I'd always been fascinated by astronomy. The truth is that just about every physicist who walks the Earth has a love for astronomy. Many physicists I know built their own telescopes when they were in high school. My longtime friend and MIT colleague George Clark ground and polished a 6-inch mirror for a telescope when he was in high school. Why do physicists love astronomy so much? For one thing, many advances in physics—theories of orbital motion, for instance—have resulted from astronomical questions, observations, and theories. But also, astronomy is physics, writ large across the night sky: eclipses, comets, shooting stars, globular clusters, neutron stars, gamma-ray bursts, jets, planetary nebulae, supernovae, clusters of galaxies, black holes.

Just look up in the sky and ask yourself some obvious questions: Why is the sky blue, why are sunsets red, why are clouds white? Physics has the answers! The light of the Sun is composed of all the colors of the rainbow. But as it makes its way through the atmosphere it scatters in all directions off air molecules and very tiny dust particles (much smaller than a micron, which is 1/250,000 of an inch). This is called Rayleigh scattering. Blue light scatters the most of all colors, about five times more than red light. Thus when you look at the sky during the day in any direction*, blue dominates, which is why the sky is blue. If you look at the sky from the surface of the Moon (you may have seen pictures), the sky is not blue—it's black, like our sky at night. Why? Because the Moon has no atmosphere.

Why are sunsets red? For exactly the same reason that the sky is blue. When the Sun is at the horizon, its rays have to travel through more atmosphere, and the green, blue, and violet light get scattered the most—filtered out of the light, basically. By the time the light reaches our eyes—and the clouds above us—it's made up largely of yellow, orange, and especially red. That's why the sky sometimes almost appears to be on fire at sunset and sunrise.

Why are clouds white? The water drops in clouds are much larger than the tiny particles that make our sky blue, and when light scatters off these much larger particles, all the colors in it scatter equally. This causes the light to stay white. But if a cloud is very thick with moisture, or if it is in the shadow of another cloud, then not much light will get through, and the cloud will turn dark.

One of the demonstrations I love to do is to create a patch of "blue sky" in my classes. I turn all the lights off and aim a very bright spotlight of white light at the ceiling of the classroom near my blackboard. The spotlight is carefully shielded. Then I light a few cigarettes and hold them in the light beam. The smoke particles are small enough to produce Rayleigh scattering, and because blue light scatters the most, the students see blue smoke. I then carry this demonstration one step further. I inhale the smoke and keep it in my lungs for a minute or so—this is not always easy, but science occasionally requires sacrifices. I then let go and exhale the smoke into the light beam. The students now see white smoke—I have created a white cloud! The tiny smoke particles have grown in my lungs, as there is a lot of water vapor there. So now all the colors scatter equally, and the scattered light is white. The color change from blue light to white light is truly amazing!

With this demonstration, I'm able to answer two questions at once: Why is the sky blue, and why are clouds white? Actually, there is also a third very interesting question, having to do with the polarization of light. I'll get to this in chapter 5.

Out in the country with my students I could show them the Andromeda galaxy, the only one you can see with the naked eye, around 2.5 million light-years away (15 million trillion miles), which is next door as far as astronomical distances go. It's made up of about 200 billion stars. Imagine that—200 billion stars, and we could just make it out as a faint fuzzy patch. We also spotted lots of meteorites—most people call them shooting stars. If you were patient, you'd see one about every four or five minutes. In those days there were no satellites, but now you'd see a host of those as well. There are more than two thousand now orbiting Earth, and if you can hold your gaze for five minutes you'll almost surely see one, especially within a few hours after sunset or before sunrise, when the Sun hasn't yet set or risen on the satellite itself and sunlight still reflects off it to your eyes. The more distant the satellite, and therefore the greater the difference in time between sunset on Earth and at the satellite, the later you can see it at night. You recognize satellites because they move faster than anything else in the sky (except meteors); if it blinks, believe me, it's an airplane.

I have always especially liked to point out Mercury to people when we're stargazing. As the planet closest to the Sun, it's very difficult to see it with the naked eye. The conditions are best only about two dozen evenings and mornings a year. Mercury orbits the Sun in just eighty-eight days, which is why it was named for the fleet-footed Roman messenger god; and the reason it's so hard to see is that its orbit is so close to the Sun. It's never more than about 25 degrees away from the Sun when we look at it from Earth—that's smaller than the angle between the two hands of a watch at eleven o'clock. You can only see it shortly after sunset and before sunrise, and when it's farthest from the Sun as seen from Earth. In the United States it's always close to the horizon; you almost have to be in the countryside to see it. How wonderful it is when you actually find it!

Stargazing connects us to the vastness of the universe. If we keep staring up at the night sky, and let our eyes adjust long enough, we can see the superstructure of the farther reaches of our own Milky Way galaxy quite beautifully—some 100 billion to 200 billion stars, clustered as if woven into a diaphanous fabric, so delightfully delicate. The size of the universe is incomprehensible, but you can begin to grasp it by first considering the Milky Way.

Our current estimate is that there may be as many galaxies in the universe as there are stars in our own galaxy. In fact, whenever a telescope observes deep space, what it sees is mostly galaxies—it's impossible to distinguish single stars at truly great distances—and each contains billions of stars. Or consider the recent discovery of the single largest structure in the known universe, the Great Wall of galaxies, mapped by the Sloan Digital Sky Survey, a major project that has combined the efforts of more than three hundred astronomers and engineers and twenty-five universities and research institutions. The dedicated Sloan telescope is observing every night; it went into operation in the year 2000 and will continue till at least the year 2014. The Great Wall is more than a billion light-years long. Is your head spinning? If not, then consider that the observable universe (not the entire universe, just the part we can observe) is roughly 90 billion light-years across.

This is the power of physics; it can tell us that our observable universe is made up of some 100 billion galaxies. It can also tell us that of all the matter in our visible universe, only about 4 percent is ordinary matter, of which stars and galaxies (and you and I) are made. About 23 percent is what's called dark matter (it's invisible). We know it exists, but we don't know what it is. The remaining 73 percent, which is the bulk of the energy in our universe, is called dark energy, which is also invisible. No one has a clue what that is either. The bottom line is that we're ignorant about 96 percent of the mass/energy in our universe. Physics has explained so much, but we still have many mysteries to solve, which I find very inspiring.

Physics explores unimaginable immensity, but at the same time it can dig down into the very smallest realms, to the very bits of matter such as neutrinos, as small as a tiny fraction of a proton. That is where I was spending most of my time in my early days in the field, in the realms of the very small, measuring and mapping the release of particles and radiation from radioactive nuclei. This was nuclear physics, but not the bomb-making variety. I was studying what made matter tick at a really basic level.

You probably know that almost all the matter you can see and touch is made up of elements, such as hydrogen, oxygen, and carbon combined into molecules, and that the smallest unit of an element is an atom, made up of a nucleus and electrons. A nucleus, recall, consists of protons and neutrons. The lightest and most plentiful element in the universe, hydrogen, has one proton and one electron. But there is a form of hydrogen that has a neutron as well as a proton in its nucleus. That is an isotope of hydrogen, a different form of the same element; it's called deuterium. There's even a third isotope of hydrogen, with two neutrons joining the proton in the nucleus; that's called tritium. All isotopes of a given element have the same number of protons, but a different number of neutrons, and elements have different numbers of isotopes. There are thirteen isotopes of oxygen, for instance, and thirty-six isotopes of gold.

Now, many of these isotopes are stable—that is, they can last more or less forever. But most are unstable, which is another way of saying they're radioactive, and radioactive isotopes decay: that is to say, sooner or later they transform themselves into other elements. Some of the elements they transform into are stable, and then the radioactive decay stops, but others are unstable, and then the decay continues until a stable state is reached. Of the three isotopes of hydrogen, only one, tritium, is radioactive—it decays into a stable isotope of helium. Of the thirteen isotopes of oxygen, three are stable; of gold's thirty-six isotopes, only one is stable.

You will probably remember that we measure how quickly radioactive isotopes decay by their "half-life"—which can range from a microsecond (one-millionth of a second) to billions of years. If we say that tritium has a half-life of about twelve years, we mean that in a given sample of tritium, half of the isotopes will decay in twelve years (only one-quarter will remain after twenty-four years). Nuclear decay is one of the most important processes by which many different elements are transformed and created. It's not alchemy. In fact, during my PhD research, I was often watching radioactive gold isotopes decay into mercury rather than the other way around, as the medieval alchemists would have liked. There are, however, many isotopes of mercury, and also of platinum, that decay into gold. But only one platinum isotope and only one mercury isotope decay into stable gold, the kind you can wear on your finger.

The work was immensely exciting; I would have radioactive isotopes literally decaying in my hands. And it was very intense. The isotopes I was working with typically had half-lives of only a day or a few days. Gold-198, for instance, has a half-life of a little over two and a half days, so I had to work fast. I would drive from Delft to Amsterdam, where they used a cyclotron to make these isotopes, and rush back to the lab at Delft. There I would dissolve the isotopes in an acid to get them into liquid form, put them on very thin film, and place them into detectors.

I was trying to verify a theory about nuclear decay, one that predicted the ratio of gamma ray to electron emissions from the nuclei, and my work required precise measurements. This work had already been done for many radioactive isotopes, but some recent measurements had come out that were different from what the theory predicted. My supervisor, Professor Aaldert Wapstra, suggested I try to determine whether it was the theory or the measurements that were at fault. It was enormously satisfying, like working on a fantastically intricate puzzle. The challenge was that my measurements had to be much more precise than the ones those other researchers had come up with before me.

Electrons are so small that some say they have no effective size—they're less than a thousand-trillionth of a centimeter across—and gamma rays have a wavelength of less than a billionth of a centimeter. And yet physics had provided me with the means to detect and to count them. That's yet another thing that I love about experimental physics; it lets us "touch" the invisible.

To get the measurements I needed, I had to milk the sample as long as I could, because the more counts I had, the greater my precision would be. I'd frequently be working for something like 60 hours straight, often without sleeping. I became a little obsessed.

For an experimental physicist, precision is key in everything. The accuracy is the only thing that matters, and a measurement that doesn't also indicate its degree of accuracy is meaningless. This simple, powerful, totally fundamental idea is almost always ignored in college books about physics. Knowing degrees of accuracy is critical to so many things in our lives.

In my work with radioactive isotopes, attaining the degree of accuracy I had to achieve was very challenging, but over three or four years I got better and better at the measurements. After I improved some of the detectors, they turned out to be extremely accurate. I was confirming the theory, and publishing my results, and this work ended up being my PhD thesis. What was especially satisfying to me was that my results were rather conclusive, which doesn't happen very often. Many times in physics, and in science generally, results are not always clear-cut. I was fortunate to arrive at a firm conclusion. I had solved a puzzle and established myself as a physicist, and I had helped to chart the unknown territory of the subatomic world. I was twenty-nine years old, and I was thrilled to be making a solid contribution. Not all of us are destined to make gigantic fundamental discoveries like Newton and Einstein did, but there's an awful lot of territory that is still ripe for exploration.

I was also fortunate that at the time I got my degree, a whole new era of discovery about the nature of the universe was getting under way. Astronomers were making discoveries at an amazing pace. Some were examining the atmospheres of Mars and Venus, searching for water vapor. Some had discovered the belts of charged particles circling the Earth's magnetic field lines, which we now call the Van Allen belts. Others had discovered huge, powerful sources of radio waves known as quasars (quasi-stellar radio sources). The cosmic microwave background (CMB) radiation was discovered in 1965—the traces of the energy released by the big bang, powerful evidence for the big bang theory of the universe's origin, which had been controversial. Shortly after, in 1967, astronomers would discover a new category of stars, which came to be called pulsars.

I might have continued working in nuclear physics, as there was a great deal of discovery going on there as well. This work was mostly in the hunt for and discovery of a rapidly growing zoo of subatomic particles, most importantly those called quarks, which turned out to be the building blocks of protons and neutrons. Quarks are so odd in their range of behaviors that in order to classify them, physicists assigned them what they called flavors: up, down, strange, charm, top, and bottom. The discovery of quarks was one of those beautiful moments in science when a purely theoretical idea is confirmed. Theorists had predicted quarks, and then experimentalists managed to find them. And how exotic they were, revealing that matter was so much more complicated in its foundations than we had known. For instance, we now know that protons consist of two up quarks and one down quark, held together by the strong nuclear force, in the form of other strange particles called gluons. Some theoreticians have recently calculated that the up quark seems to have a mass of about 0.2 percent of that of a proton, while the down quark has a mass of about 0.5 percent of the mass of a proton. This was not your grandfather's nucleus anymore. The particle zoo would have been a fascinating area of research to go into, I'm sure, but by a happy accident, the skills I'd learned for measuring radiation emitted from the nucleus turned out to be extremely useful for probing the universe. In 1965, I received an invitation from Professor Bruno Rossi at MIT to work on X-ray astronomy, which was an entirely new field, really just a few years old at the time—Rossi had initiated it in 1959.

MIT was the best thing that could ever have happened to me. Rossi's work on cosmic rays was already legendary. He'd headed a department at Los Alamos during the war and pioneered in the measurements of solar wind, also called interplanetary plasma—a stream of charged particles ejected by the Sun that causes our aurora borealis and "blows" comet tails away from the Sun. Now he had the idea to search the cosmos for X-rays. It was completely exploratory work; he had no idea whether he'd find them or not.

Anything went at that time at MIT. Any idea you had, if you could convince people that it was doable, you could work on it. What a difference from the Netherlands! At Delft, there was a rigid hierarchy, and the graduate students were treated like a lower class. The professors were given keys to the front door of my building, but as a graduate student you only got a key to the door in the basement, where the bicycles were kept. Each time you entered the building you had to pick your way through the bicycle storage rooms and be reminded of the fact that you were nothing.

If you wanted to work after five o'clock you had to fill out a form, every day, by four p.m., justifying why you had to stay late, which I had to do almost all the time. The bureaucracy was a real nuisance.

The three professors in charge of my institute had reserved parking places close to the front door. One of them, my own supervisor, worked in Amsterdam and came to Delft only once a week on Tuesdays. I asked him one day, “When you are not here, would you mind if I used your parking space?” He said, “Of course not,” but then the very first day I parked there I was called on the public intercom and instructed in the strongest terms possible that I was to remove my car. Here’s another one. Since I had to go to Amsterdam to pick up my isotopes, I was allowed 25 cents for a cup of coffee, and 1.25 guilders for lunch (1.25 guilders was about one-third of a U.S. dollar at the time), but I had to submit separate receipts for each. So I asked if I could add the 25 cents to the lunch receipt and only submit one receipt for 1.50 guilders. The department chair, Professor Blaisse, wrote me a letter that stated that if I wanted to have gourmet meals I could do so—at my own expense.

So what a joy it was to get to MIT and be free from all of that; I felt reborn. Everything was done to encourage you. I got a key to the front door and could work in my office day or night just as I wanted. To me, that key to the building was like a key to everything. The head of the Physics Department offered me a faculty position six months after my arrival, in June of 1966. I accepted and I’ve never left.

Arriving at MIT was also so exhilarating because I had lived through the devastation of World War II. The Nazis had murdered half of my family, a tragedy that I haven’t really digested yet. I do talk about it sometimes, but very rarely because it’s so very difficult for me—it is more than sixty-five years ago, and it’s still overwhelming. When my sister Bea and I talk about it, we almost always cry.

I was born in 1936, and I was just four years old when the Germans attacked the Netherlands on May 10, 1940. One of my earliest memories is all of us, my mother’s parents, my mother and father and sister and I, hiding in the bathroom of our house (at the Amandelstraat 61 in The Hague) as the Nazi troops entered my country. We were holding wet handkerchiefs over our noses, as there had been warnings that there would be gas attacks.

The Dutch police snatched my Jewish grandparents, Gustav Lewin and Emma Lewin Gottfeld, from their house in 1942. At about the same time they hauled out my father’s sister Julia, her husband Jacob (called Jenno), and her three children—Otto, Rudi, and Emmie—and put them all on trucks, with their suitcases, and sent them to Westerbork, the transshipment camp in Holland. More than a hundred thousand Jews passed through Westerbork, on their way to other camps. The Nazis quickly sent my grandparents to Auschwitz and murdered them—gassed them—the day they arrived, November 19, 1942. My grandfather was seventy-five and my grandmother sixty-nine, so they wouldn’t have been candidates for labor camps. Westerbork, by contrast, was so strange; it was made to look like a resort for Jews. There were ballet performances and shops. My mother would often bake potato pancakes that she would then send by mail to our family in Westerbork.

Because my uncle Jenno was what the Dutch call “statenloos,” or stateless—he had no nationality—he was able to drag his feet and stay at Westerbork with his family for fifteen months before the Nazis split up the family and shipped them to different camps. They sent my aunt Julia and my cousins Emmie and Rudi first to the women’s concentration camp Ravensbrück in Germany and then to Bergen-Belsen, also in Germany, where they were imprisoned until the war ended. My aunt Julia died ten days after the camp’s liberation by the Allies, but my cousins survived. My cousin Otto, the oldest, had also been sent to Ravensbrück, to the men’s camp there, and near the end of the war ended up in the concentration camp in Sachsenhausen; he survived the Sachsenhausen death march in April 1945. Uncle Jenno they sent directly to Buchenwald, where they murdered him—along with more than 55,000 others.

Whenever I see a movie about the Holocaust, which I would not do for a really long time, I project it immediately onto my own family. That's why I felt the movie Life Is Beautiful was terribly difficult to watch, even objectionable. I just couldn't imagine joking about something that was so serious. I still have recurring nightmares about being chased by Nazis, and I wake up sometimes absolutely terrified. I even once in my dreams witnessed my own execution by the Nazis.

Some day I would like to take the walk, my paternal grandparents' last walk, from the train station to the gas chambers at Auschwitz. I don't know if I'll ever do it, but it seems to me like one way to memorialize them. Against such a monstrosity, maybe small gestures are all that we have. That, and our refusal to forget: I never talk about my family members having "died" in concentration camps. I always use the word murdered, so we do not let language hide the reality.

My father was Jewish but my mother was not, and as a Jew married to a non-Jewish woman, he was not immediately a target. But he became a target soon enough, in 1943. I remember that he had to wear the yellow star. Not my mother, or sister, or I, but he did. We didn't pay much attention to it, at least not at first. He had it hidden a little bit, under his clothes, which was forbidden. What was really frightening was the way he gradually accommodated to the Nazi restrictions, which just kept getting worse. First, he was not allowed on public transportation. Then, he wasn't allowed in public parks. Then he wasn't allowed in restaurants; he became persona non grata in places he had frequented for years! And the incredible thing is the ability of people to adjust.

When he could no longer take public transportation, he would say, "Well, how often do I make use of public transportation?" When he wasn't allowed in public parks anymore, he would say, "Well, how often do I go to public parks?" Then, when he could not go to a restaurant, he would say, "Well, how often do I go to restaurants?" He tried to make these awful things seem trivial, like a minor inconvenience, perhaps for his children's sake, and perhaps also for his own peace of mind. I don't know.

It's still one of the hardest things for me to talk about. Why this ability to slowly see the water rise but not recognize that it will drown you? How could they see it and not see it at the same time? That's something that I cannot cope with. Of course, in a sense it's completely understandable; perhaps that's the only way you can survive, for as long as you are able to fool yourself.

Though the Nazis made public parks off-limits to Jews, my father was allowed to walk in cemeteries. Even now, I recall many walks with him at a nearby cemetery. We fantasized about how and why family members died—sometimes four had died on the same day. I still do that nowadays when I walk in Cambridge's famous Mount Auburn Cemetery.

The most dramatic thing that happened to me growing up was that all of a sudden my father disappeared. I vividly remember the day he left. I came home from school and sensed somehow that he was gone. My mother was not home, so I asked our nanny, Lenie, "Where's Dad?" and I got an answer of some sort, meant to be reassuring, but somehow I knew that my father had left.

Bea saw him leaving, but she never told me until many years later. The four of us slept in the same bedroom for security, and at four in the morning, she saw him get up and put some clothes in a bag. Then he kissed my mother and left. My mother didn't know where he was going; that knowledge would have been very dangerous, because the Germans might have tortured her to find out where my father was and she would have told them. We now know that the Resistance hid him, and eventually we got some messages from him through the Resistance, but at the time it was absolutely terrible not knowing where he was or even if he was alive.

I was too young to understand how profoundly his absence affected my mother. My parents ran a school out of our home—which no doubt had a strong influence on my love of teaching—and she struggled to carry on without him. She had a tendency toward depression anyway, but now her husband was gone, and she worried that we children might be sent to a concentration camp. She must have been truly terrified for us because—as she told me fifty-five years later—one night she said to Bea and me that we should sleep in the kitchen, and she stuffed curtains and blankets and towels under the doors so that no air could escape. She was intending to put the gas on and let us sleep ourselves into death, but she didn't go through with it. Who can blame her for thinking of it—I know that Bea and I don't.

I was afraid a lot. And I know it sounds ridiculous, but I was the only male, so I sort of became the man of the house, even at age seven and eight. In The Hague, where we lived, there were many broken-down houses on the coast, half-destroyed by the Germans who were building bunkers on our beaches. I would go there and steal wood—I was going to say "collect," but it was stealing—from those houses so that we had some fuel for cooking and for heat.

To try to stay warm in the winters we wore this rough, scratchy, poor-quality wool. And I still cannot stand wool to this day. My skin is so sensitive that I sleep on eight-hundred-thread-count cotton sheets. That's also why I order very fine cotton shirts—ones that do not irritate my skin. My daughter Pauline tells me that if I see her wearing wool, I still turn away; such is the effect the war still has on me.

My father returned while the war was still going on, in the fall of 1944. People in my family disagree about just how this happened, but as near as I can tell it seems that my wonderful aunt Lauk, my mother's sister, was in Amsterdam one day, about 30 miles away from The Hague, and she caught sight of my father! She followed him from a distance and saw him go into a house. Later she went back and discovered that he was living with a woman.

My aunt told my mother, who at first got even more depressed and upset, but I'm told that she collected herself and took the boat to Amsterdam (trains were no longer operating), marched right up to the house, and rang the bell. Out came the woman, and my mother said, "I want to speak to my husband." The woman replied, "I am the wife of Mr. Lewin." But my mother insisted: "I want my husband." My father came to the door, and she said, "I'll give you five minutes to pack up and come back with me or else you can get a divorce and you'll never see your children again." In three minutes he came back downstairs with his things and returned with her.

In some ways it was much worse when he was back, because people knew that my father, whose name was also Walter Lewin, was a Jew. The Resistance had given him false identification papers, under the name of Jaap Horstman, and my sister and I were instructed to call him Uncle Jaap. It's a total miracle, and doesn't make any sense to Bea and me to this very day, but no one turned him in. A carpenter made a hatch in the ground floor of our house. We could lift it up and my father could go down and hide in the crawl space. Remarkably, my father managed to avoid capture.

He was probably at home eight months or so before the war ended, including the worst time of the war for us, the winter of 1944 famine, the hongerwinter. People starved to death—nearly twenty thousand died. For heat we crawled under the house and pulled out every other floor joist—the large beams that supported the ground floor—for firewood. In the hunger winter we ate tulip bulbs, and even bark. People could have turned my father in for food. The Germans would also pay money (I believe it was fifty guilders, which was about fifteen dollars at the time) for every Jew they turned in.

The Germans did come to our house one day. It turned out that they were collecting typewriters, and they looked at ours, the ones we used to teach typing, but they thought they were too old. The Germans in their own way were pretty stupid; if you're being told to collect typewriters, you don't collect Jews. It sounds like a movie, I know. But it really happened.

After all of the trauma of the war, I suppose the amazing thing is that I had a more or less normal childhood. My parents kept running their school—the Haagsch Studiehuis—which they'd done before and during the war, teaching typing, shorthand, languages, and business skills. I too was a teacher there while I was in college.

My parents patronized the arts, and I began to learn about art. I had an academically and socially wonderful time in college. I got married in 1959, started graduate school in January 1960, and my first daughter, Pauline, was born later that year. My son Emanuel (who is now called Chuck) was born two years after that, and our second daughter, Emma, came in 1965. Our second son, Jakob, was born in the United States in 1967.

When I arrived at MIT, luck was on my side; I found myself right in the middle of the explosion of discoveries going on at that time. The expertise I had to offer was perfect for Bruno Rossi's pioneering X-ray astronomy team, even though I didn't know anything about space research.

V-2 rockets had broken the bounds of the Earth's atmosphere, and a whole new vista of opportunity for discoveries had been opened up. Ironically, the V-2 had been designed by Wernher von Braun, who was a Nazi. He developed the rockets during World War II to kill Allied civilians, and they were terribly destructive. In Peenemünde and in the notorious underground Mittelwerk plant in Germany, slave laborers from concentration camps built them, and some twenty thousand died in the process. The rockets themselves killed more than seven thousand civilians, mostly in London. There was a launch site about a mile from my mother's parents' house close to The Hague. I recall a sizzling noise as the rockets were being fueled and the roaring noise at launch. In one bombing raid the Allies tried to destroy V-2 equipment, but they missed and killed five hundred Dutch civilians instead. After the war the Americans brought von Braun to the United States and he became a hero. That has always baffled me. He was a war criminal!

For fifteen years von Braun worked with the U.S. Army to build the V-2's descendants, the Redstone and Jupiter missiles, which carried nuclear warheads. In 1960 he joined NASA and directed the Marshall Space Flight Center in Alabama, where he developed the Saturn rockets that sent astronauts to the Moon. Descendants of his rockets launched the field of X-ray astronomy, so while rockets began as weapons, at least they also got used for a great deal of science. In the late 1950s and early 1960s they opened new windows on the world—no, on the universe!—giving us the chance to peek outside of the Earth's atmosphere and look around for things we couldn't see otherwise.

To discover X-rays from outer space, Rossi had played a hunch. In 1959 he went to an ex-student of his named Martin Annis, who then headed a research firm in Cambridge called American Science and Engineering, and said, "Let's just see if there are X-rays out there." The ASE team, headed by future Nobelist Riccardo Giacconi, put three Geiger-Müller counters in a rocket that they launched on June 18, 1962. It spent just six minutes above 80 kilometers (about 50 miles), to get beyond the Earth's atmosphere—a necessity, since the atmosphere absorbs X-rays.

Sure enough, they detected X-rays, and even more important, they were able to establish that the X-rays came from a source outside the solar system. It was a bombshell that changed all of astronomy. No one expected it, and no one could think of plausible reasons why they were there; no one really understood the finding. Rossi had been throwing an idea at the wall to see if it would stick. These are the kinds of hunches that make a great scientist.

I remember the exact date I arrived at MIT, January 11, 1966, because one of our kids got the mumps and we had to delay going to Boston; the KLM wouldn't let us fly, as the mumps is contagious. On my first day I met Bruno Rossi and also George Clark, who in 1964 had been the first to fly a balloon at a very high altitude—about 140,000 feet—to search for X-ray sources that emitted very high energy X-rays, the kind that could penetrate down to that altitude. George said, "If you want to join my group that would be great." I was at exactly the right place at the right time.

If you're the first to do something, you're bound to be successful, and our team made one discovery after another. George was very generous; after two years he turned the group completely over to me. To be on the cutting edge of the newest wave in astrophysics was just remarkable.

I was incredibly fortunate to find myself right in the thick of the most exciting work going on in astrophysics at that time, but the truth is that all areas of physics are amazing; all are filled with intriguing delights and are revealing astonishing new discoveries all the time. While we were finding new X-ray sources, particle physicists were finding ever more fundamental building blocks of the nucleus, solving the mystery of what holds nuclei together, discovering the W and Z bosons, which carry the "weak" nuclear interactions, and quarks and gluons, which carry the "strong" interactions.

Physics has allowed us to see far back in time, to the very edges of the universe, and to make the astonishing image known as the Hubble Ultra Deep Field, revealing what seems an infinity of galaxies. You should not finish this chapter without looking up the Ultra Deep Field online. I have friends who've made this image their screen saver!

The universe is about 13.7 billion years old. However, due to the fact that space itself has expanded enormously since the big bang, we are currently observing galaxies that were formed some 400 to 800 million years after the big bang and that are now considerably farther away than 13.7 billion light-years. Astronomers now estimate that the edge of the observable universe is about 47 billion light-years away from us in every direction. Because of the expansion of space, many faraway galaxies are currently moving away from us faster than the speed of light. This may sound shocking, even impossible, to those of you raised on the notion that, as Einstein postulated in his theory of special relativity, nothing can go faster than the speed of light. However, according to Einstein's theory of general relativity, there are no limits on the speed between two galaxies when space itself is expanding. There are good reasons why scientists now think that we are living in the golden age of cosmology—the study of the origin and evolution of the entire universe.

Physics has explained the beauty and fragility of rainbows, the existence of black holes, why the planets move the way they do, what goes on when a star explodes, why a spinning ice skater speeds up when she draws in her arms, why astronauts are weightless in space, how elements were formed in the universe, when our universe began, how a flute makes music, how we generate electricity that drives our bodies as well as our economy, and what the big bang sounded like. It has charted the smallest reaches of subatomic space and the farthest reaches of the universe.

My friend and colleague Victor Weisskopf, who was already an elder statesman when I arrived at MIT, wrote a book called The Privilege of Being a Physicist. That wonderful title captures the feelings I've had being smack in the middle of one of the most exciting periods of astronomical and astrophysical discovery since men and women started looking carefully at the night sky. The people I've worked alongside at MIT, sometimes right across the hall from me, have devised astonishingly creative and sophisticated techniques to hammer away at the most fundamental questions in all of science. And it's been my own privilege both to help extend humankind's collective knowledge of the stars and the universe and to bring several generations of young people to an appreciation and love for this magnificent field.

Ever since those early days of holding decaying isotopes in the palm of my hand, I have never ceased to be delighted by the discoveries of physics, both old and new; by its rich history and ever-moving frontiers; and by the way it has opened my eyes to unexpected wonders of the world all around me. For me physics is a way of seeing—the spectacular and the mundane, the immense and the minute—as a beautiful, thrillingly interwoven whole.

That is the way I've always tried to make physics come alive for my students. I believe it's much more important for them to remember the beauty of the discoveries than to focus on the complicated math—after all, most of them aren't going to become physicists. I have done my utmost to help them see the world in a different way; to ask questions they've never thought to ask before; to allow them to see rainbows in a way they have never seen before; and to focus on the exquisite beauty of physics, rather than on the minutiae of the mathematics. That is also the intention of this book, to help open your eyes to the remarkable ways in which physics illuminates the workings of our world and its astonishing elegance and beauty.

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FOR THE LOVE OF PHYSICS: FROM THE END OF THE RAINBOW TO THE EDGE OF TIME - A JOURNEY THROUGH THE WONDERS OF PHYSICS BY WALTER LEWIN PDF

Beloved MIT professor Walter Lewin, whose riveting physics lectures have made him a YouTube super-star, offers a mind-opening and delightful journey through the most intriguing discoveries in physics. A wonderful raconteur, Lewin takes readers on a marvellous journey with him in For the Love of Physics, opening our eyes as never before to the amazing beauty and power of all that physics can reveal to us. He describes the coolest, weirdest facets of the tiniest bits of matter, the wonders of our everyday lives-such as the mysteries of why lighting strikes and what makes musical harmony happen-and the most awesome features of the outer reaches of the universe. Whether explaining why the air smells so fresh after a lightning storm or showing us that a flea is strong enough to pull a heavy book across a table, Lewin always entertains as he edifies. For the Love of Physics is a rare gem that will change the way readers see the world.

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Review
"MIT's Lewin is deservedly popular for his memorable physics lectures (both live and on MIT's Open Course Web site and YouTube), and this quick-paced autobiography-cum-physics intro fully captures his candor and lively teaching style...joyful...[this text] glows with energy and should please a wide range of readers."--"Publishers Weekly" (starred review)

About the Author
Walter Lewin taught the three core classes in physics at MIT for more than thirty years and made major discoveries in the area of X-ray astronomy. His physics lectures have been the subject of great acclaim, including a 60 Minutes feature, stories in the New York Times, Washington Post, Boston Globe, Newsweek and US News and World Report. They have also been top draws on YouTube and iTunes University. He was awarded three prizes for excellence in undergraduate teaching. He has published more than 450 scientific articles, and his honors and awards include the NASA Award for Exceptional Scientific Achievement, the Alexander von Humboldt Award, and a Guggenheim Fellowship. He became a corresponding member of the Royal Netherlands Academy of Arts and Sciences and Fellow of the American Physical Society in 1993. He lives in Cambridge, Massachusetts.

Warren Goldstein is a professor of history and chair of the History Department at the University of Hartford. A prizewinning historian, essayist, and journalist, he has had a lifelong fascination with physics. His writing has appeared in the New York Times, Washington Post, Boston Globe, Chicago Tribune and many other national periodicals. His prior books include Playing for Keeps: A History of Early Baseball and William Sloane Coffin, Jr.: A Holy Impatience.

For the Love of Physics CHAPTER 1

From the Nucleus to Deep Space

It's amazing, really. My mother's father was illiterate, a custodian. Two generations later I'm a full professor at MIT. I owe a lot to the Dutch educational system. I went to graduate school at the Delft University of Technology in the Netherlands, and killed three birds with one stone.

Right from the start, I began teaching physics. To pay for school I had to take out a loan from the Dutch government, and if I taught full time, at least twenty hours a week, each year the government would forgive one-fifth of my loan. Another advantage of teaching was that I wouldn't have to serve in the army. The military would have been the worst, an absolute disaster for me. I'm allergic to all forms of authority—it's just in my personality—and I knew I would have ended up mouthing off and scrubbing floors. So I taught math and physics full time, twenty-two contact hours per week, at the Libanon Lyceum in Rotterdam, to sixteen-and seventeen-year-olds. I avoided the army, did not have to pay back my loan, and was getting my PhD, all at the same time.

I also learned to teach. For me, teaching high school students, being able to change the minds of young people in a positive way, that was thrilling. I always tried to make classes interesting but also fun for the students, even though the school itself was quite strict. The classroom doors had transom windows at the top, and one of the headmasters would sometimes climb up on a chair and spy on teachers through the transom. Can you believe it?

I wasn't caught up in the school culture, and being in graduate school, I was boiling over with enthusiasm. My goal was to impart that enthusiasm to my students, to help them see the beauty of the world all around them in a new way, to change them so that they would see the world of physics as beautiful, and would understand that physics is everywhere, that it permeates our lives. What counts, I found, is not what you cover, but what you uncover. Covering subjects in a class can be a boring exercise, and students feel it. Uncovering the laws of physics and making them see through the equations, on the other hand, demonstrates the process of discovery, with all its newness and excitement, and students love being part of it.

I got to do this also in a different way far outside the classroom. Every year the school sponsored a week-long vacation when a teacher would take the kids on a trip to a fairly remote and primitive campsite. My wife, Huibertha, and I did it once and loved it. We all cooked together and slept in tents. Then, since we were so far from city lights, we woke all the kids up in the middle of one night, gave them hot chocolate, and took them out to look at the stars. We identified constellations and planets and they got to see the Milky Way in its full glory.

I wasn't studying or even teaching astrophysics—in fact, I was designing experiments to detect some of the smallest particles in the universe—but I'd always been fascinated by astronomy. The truth is that just about every physicist who walks the Earth has a love for astronomy. Many physicists I know built their own telescopes when they were in high school. My longtime friend and MIT colleague George Clark ground and polished a 6-inch mirror for a telescope when he was in high school. Why do physicists love astronomy so much? For one thing, many advances in physics—theories of orbital motion, for instance—have resulted from astronomical questions, observations, and theories. But also, astronomy is physics, writ large across the night sky: eclipses, comets, shooting stars, globular clusters, neutron stars, gamma-ray bursts, jets, planetary nebulae, supernovae, clusters of galaxies, black holes.

Just look up in the sky and ask yourself some obvious questions: Why is the sky blue, why are sunsets red, why are clouds white? Physics has the answers! The light of the Sun is composed of all the colors of the rainbow. But as it makes its way through the atmosphere it scatters in all directions off air molecules and very tiny dust particles (much smaller than a micron, which is 1/250,000 of an inch). This is called Rayleigh scattering. Blue light scatters the most of all colors, about five times more than red light. Thus when you look at the sky during the day in any direction*, blue dominates, which is why the sky is blue. If you look at the sky from the surface of the Moon (you may have seen pictures), the sky is not blue—it's black, like our sky at night. Why? Because the Moon has no atmosphere.

Why are sunsets red? For exactly the same reason that the sky is blue. When the Sun is at the horizon, its rays have to travel through more atmosphere, and the green, blue, and violet light get scattered the most—filtered out of the light, basically. By the time the light reaches our eyes—and the clouds above us—it's made up largely of yellow, orange, and especially red. That's why the sky sometimes almost appears to be on fire at sunset and sunrise.

Why are clouds white? The water drops in clouds are much larger than the tiny particles that make our sky blue, and when light scatters off these much larger particles, all the colors in it scatter equally. This causes the light to stay white. But if a cloud is very thick with moisture, or if it is in the shadow of another cloud, then not much light will get through, and the cloud will turn dark.

One of the demonstrations I love to do is to create a patch of "blue sky" in my classes. I turn all the lights off and aim a very bright spotlight of white light at the ceiling of the classroom near my blackboard. The spotlight is carefully shielded. Then I light a few cigarettes and hold them in the light beam. The smoke particles are small enough to produce Rayleigh scattering, and because blue light scatters the most, the students see blue smoke. I then carry this demonstration one step further. I inhale the smoke and keep it in my lungs for a minute or so—this is not always easy, but science occasionally requires sacrifices. I then let go and exhale the smoke into the light beam. The students now see white smoke—I have created a white cloud! The tiny smoke particles have grown in my lungs, as there is a lot of water vapor there. So now all the colors scatter equally, and the scattered light is white. The color change from blue light to white light is truly amazing!

With this demonstration, I'm able to answer two questions at once: Why is the sky blue, and why are clouds white? Actually, there is also a third very interesting question, having to do with the polarization of light. I'll get to this in chapter 5.

Out in the country with my students I could show them the Andromeda galaxy, the only one you can see with the naked eye, around 2.5 million light-years away (15 million trillion miles), which is next door as far as astronomical distances go. It's made up of about 200 billion stars. Imagine that—200 billion stars, and we could just make it out as a faint fuzzy patch. We also spotted lots of meteorites—most people call them shooting stars. If you were patient, you'd see one about every four or five minutes. In those days there were no satellites, but now you'd see a host of those as well. There are more than two thousand now orbiting Earth, and if you can hold your gaze for five minutes you'll almost surely see one, especially within a few hours after sunset or before sunrise, when the Sun hasn't yet set or risen on the satellite itself and sunlight still reflects off it to your eyes. The more distant the satellite, and therefore the greater the difference in time between sunset on Earth and at the satellite, the later you can see it at night. You recognize satellites because they move faster than anything else in the sky (except meteors); if it blinks, believe me, it's an airplane.

I have always especially liked to point out Mercury to people when we're stargazing. As the planet closest to the Sun, it's very difficult to see it with the naked eye. The conditions are best only about two dozen evenings and mornings a year. Mercury orbits the Sun in just eighty-eight days, which is why it was named for the fleet-footed Roman messenger god; and the reason it's so hard to see is that its orbit is so close to the Sun. It's never more than about 25 degrees away from the Sun when we look at it from Earth—that's smaller than the angle between the two hands of a watch at eleven o'clock. You can only see it shortly after sunset and before sunrise, and when it's farthest from the Sun as seen from Earth. In the United States it's always close to the horizon; you almost have to be in the countryside to see it. How wonderful it is when you actually find it!

Stargazing connects us to the vastness of the universe. If we keep staring up at the night sky, and let our eyes adjust long enough, we can see the superstructure of the farther reaches of our own Milky Way galaxy quite beautifully—some 100 billion to 200 billion stars, clustered as if woven into a diaphanous fabric, so delightfully delicate. The size of the universe is incomprehensible, but you can begin to grasp it by first considering the Milky Way.

Our current estimate is that there may be as many galaxies in the universe as there are stars in our own galaxy. In fact, whenever a telescope observes deep space, what it sees is mostly galaxies—it's impossible to distinguish single stars at truly great distances—and each contains billions of stars. Or consider the recent discovery of the single largest structure in the known universe, the Great Wall of galaxies, mapped by the Sloan Digital Sky Survey, a major project that has combined the efforts of more than three hundred astronomers and engineers and twenty-five universities and research institutions. The dedicated Sloan telescope is observing every night; it went into operation in the year 2000 and will continue till at least the year 2014. The Great Wall is more than a billion light-years long. Is your head spinning? If not, then consider that the observable universe (not the entire universe, just the part we can observe) is roughly 90 billion light-years across.

This is the power of physics; it can tell us that our observable universe is made up of some 100 billion galaxies. It can also tell us that of all the matter in our visible universe, only about 4 percent is ordinary matter, of which stars and galaxies (and you and I) are made. About 23 percent is what's called dark matter (it's invisible). We know it exists, but we don't know what it is. The remaining 73 percent, which is the bulk of the energy in our universe, is called dark energy, which is also invisible. No one has a clue what that is either. The bottom line is that we're ignorant about 96 percent of the mass/energy in our universe. Physics has explained so much, but we still have many mysteries to solve, which I find very inspiring.

Physics explores unimaginable immensity, but at the same time it can dig down into the very smallest realms, to the very bits of matter such as neutrinos, as small as a tiny fraction of a proton. That is where I was spending most of my time in my early days in the field, in the realms of the very small, measuring and mapping the release of particles and radiation from radioactive nuclei. This was nuclear physics, but not the bomb-making variety. I was studying what made matter tick at a really basic level.

You probably know that almost all the matter you can see and touch is made up of elements, such as hydrogen, oxygen, and carbon combined into molecules, and that the smallest unit of an element is an atom, made up of a nucleus and electrons. A nucleus, recall, consists of protons and neutrons. The lightest and most plentiful element in the universe, hydrogen, has one proton and one electron. But there is a form of hydrogen that has a neutron as well as a proton in its nucleus. That is an isotope of hydrogen, a different form of the same element; it's called deuterium. There's even a third isotope of hydrogen, with two neutrons joining the proton in the nucleus; that's called tritium. All isotopes of a given element have the same number of protons, but a different number of neutrons, and elements have different numbers of isotopes. There are thirteen isotopes of oxygen, for instance, and thirty-six isotopes of gold.

Now, many of these isotopes are stable—that is, they can last more or less forever. But most are unstable, which is another way of saying they're radioactive, and radioactive isotopes decay: that is to say, sooner or later they transform themselves into other elements. Some of the elements they transform into are stable, and then the radioactive decay stops, but others are unstable, and then the decay continues until a stable state is reached. Of the three isotopes of hydrogen, only one, tritium, is radioactive—it decays into a stable isotope of helium. Of the thirteen isotopes of oxygen, three are stable; of gold's thirty-six isotopes, only one is stable.

You will probably remember that we measure how quickly radioactive isotopes decay by their "half-life"—which can range from a microsecond (one-millionth of a second) to billions of years. If we say that tritium has a half-life of about twelve years, we mean that in a given sample of tritium, half of the isotopes will decay in twelve years (only one-quarter will remain after twenty-four years). Nuclear decay is one of the most important processes by which many different elements are transformed and created. It's not alchemy. In fact, during my PhD research, I was often watching radioactive gold isotopes decay into mercury rather than the other way around, as the medieval alchemists would have liked. There are, however, many isotopes of mercury, and also of platinum, that decay into gold. But only one platinum isotope and only one mercury isotope decay into stable gold, the kind you can wear on your finger.

The work was immensely exciting; I would have radioactive isotopes literally decaying in my hands. And it was very intense. The isotopes I was working with typically had half-lives of only a day or a few days. Gold-198, for instance, has a half-life of a little over two and a half days, so I had to work fast. I would drive from Delft to Amsterdam, where they used a cyclotron to make these isotopes, and rush back to the lab at Delft. There I would dissolve the isotopes in an acid to get them into liquid form, put them on very thin film, and place them into detectors.

I was trying to verify a theory about nuclear decay, one that predicted the ratio of gamma ray to electron emissions from the nuclei, and my work required precise measurements. This work had already been done for many radioactive isotopes, but some recent measurements had come out that were different from what the theory predicted. My supervisor, Professor Aaldert Wapstra, suggested I try to determine whether it was the theory or the measurements that were at fault. It was enormously satisfying, like working on a fantastically intricate puzzle. The challenge was that my measurements had to be much more precise than the ones those other researchers had come up with before me.

Electrons are so small that some say they have no effective size—they're less than a thousand-trillionth of a centimeter across—and gamma rays have a wavelength of less than a billionth of a centimeter. And yet physics had provided me with the means to detect and to count them. That's yet another thing that I love about experimental physics; it lets us "touch" the invisible.

To get the measurements I needed, I had to milk the sample as long as I could, because the more counts I had, the greater my precision would be. I'd frequently be working for something like 60 hours straight, often without sleeping. I became a little obsessed.

For an experimental physicist, precision is key in everything. The accuracy is the only thing that matters, and a measurement that doesn't also indicate its degree of accuracy is meaningless. This simple, powerful, totally fundamental idea is almost always ignored in college books about physics. Knowing degrees of accuracy is critical to so many things in our lives.

In my work with radioactive isotopes, attaining the degree of accuracy I had to achieve was very challenging, but over three or four years I got better and better at the measurements. After I improved some of the detectors, they turned out to be extremely accurate. I was confirming the theory, and publishing my results, and this work ended up being my PhD thesis. What was especially satisfying to me was that my results were rather conclusive, which doesn't happen very often. Many times in physics, and in science generally, results are not always clear-cut. I was fortunate to arrive at a firm conclusion. I had solved a puzzle and established myself as a physicist, and I had helped to chart the unknown territory of the subatomic world. I was twenty-nine years old, and I was thrilled to be making a solid contribution. Not all of us are destined to make gigantic fundamental discoveries like Newton and Einstein did, but there's an awful lot of territory that is still ripe for exploration.

I was also fortunate that at the time I got my degree, a whole new era of discovery about the nature of the universe was getting under way. Astronomers were making discoveries at an amazing pace. Some were examining the atmospheres of Mars and Venus, searching for water vapor. Some had discovered the belts of charged particles circling the Earth's magnetic field lines, which we now call the Van Allen belts. Others had discovered huge, powerful sources of radio waves known as quasars (quasi-stellar radio sources). The cosmic microwave background (CMB) radiation was discovered in 1965—the traces of the energy released by the big bang, powerful evidence for the big bang theory of the universe's origin, which had been controversial. Shortly after, in 1967, astronomers would discover a new category of stars, which came to be called pulsars.

I might have continued working in nuclear physics, as there was a great deal of discovery going on there as well. This work was mostly in the hunt for and discovery of a rapidly growing zoo of subatomic particles, most importantly those called quarks, which turned out to be the building blocks of protons and neutrons. Quarks are so odd in their range of behaviors that in order to classify them, physicists assigned them what they called flavors: up, down, strange, charm, top, and bottom. The discovery of quarks was one of those beautiful moments in science when a purely theoretical idea is confirmed. Theorists had predicted quarks, and then experimentalists managed to find them. And how exotic they were, revealing that matter was so much more complicated in its foundations than we had known. For instance, we now know that protons consist of two up quarks and one down quark, held together by the strong nuclear force, in the form of other strange particles called gluons. Some theoreticians have recently calculated that the up quark seems to have a mass of about 0.2 percent of that of a proton, while the down quark has a mass of about 0.5 percent of the mass of a proton. This was not your grandfather's nucleus anymore. The particle zoo would have been a fascinating area of research to go into, I'm sure, but by a happy accident, the skills I'd learned for measuring radiation emitted from the nucleus turned out to be extremely useful for probing the universe. In 1965, I received an invitation from Professor Bruno Rossi at MIT to work on X-ray astronomy, which was an entirely new field, really just a few years old at the time—Rossi had initiated it in 1959.

MIT was the best thing that could ever have happened to me. Rossi's work on cosmic rays was already legendary. He'd headed a department at Los Alamos during the war and pioneered in the measurements of solar wind, also called interplanetary plasma—a stream of charged particles ejected by the Sun that causes our aurora borealis and "blows" comet tails away from the Sun. Now he had the idea to search the cosmos for X-rays. It was completely exploratory work; he had no idea whether he'd find them or not.

Anything went at that time at MIT. Any idea you had, if you could convince people that it was doable, you could work on it. What a difference from the Netherlands! At Delft, there was a rigid hierarchy, and the graduate students were treated like a lower class. The professors were given keys to the front door of my building, but as a graduate student you only got a key to the door in the basement, where the bicycles were kept. Each time you entered the building you had to pick your way through the bicycle storage rooms and be reminded of the fact that you were nothing.

If you wanted to work after five o'clock you had to fill out a form, every day, by four p.m., justifying why you had to stay late, which I had to do almost all the time. The bureaucracy was a real nuisance.

The three professors in charge of my institute had reserved parking places close to the front door. One of them, my own supervisor, worked in Amsterdam and came to Delft only once a week on Tuesdays. I asked him one day, "When you are not here, would you mind if I used your parking space?" He said, "Of course not," but then the very first day I parked there I was called on the public intercom and instructed in the strongest terms possible that I was to remove my car. Here's another one. Since I had to go to Amsterdam to pick up my isotopes, I was allowed 25 cents for a cup of coffee, and 1.25 guilders for lunch (1.25 guilders was about one-third of a U.S. dollar at the time), but I had to submit separate receipts for each. So I asked if I could add the 25 cents to the lunch receipt and only submit one receipt for 1.50 guilders. The department chair, Professor Blaisse, wrote me a letter that stated that if I wanted to have gourmet meals I could do so—at my own expense.

So what a joy it was to get to MIT and be free from all of that; I felt reborn. Everything was done to encourage you. I got a key to the front door and could work in my office day or night just as I wanted. To me, that key to the building was like a key to everything. The head of the Physics Department offered me a faculty position six months after my arrival, in June of 1966. I accepted and I've never left.

Arriving at MIT was also so exhilarating because I had lived through the devastation of World War II. The Nazis had murdered half of my family, a tragedy that I haven't really digested yet. I do talk about it sometimes, but very rarely because it's so very difficult for me—it is more than sixty-five years ago, and it's still overwhelming. When my sister Bea and I talk about it, we almost always cry.

I was born in 1936, and I was just four years old when the Germans attacked the Netherlands on May 10, 1940. One of my earliest memories is all of us, my mother's parents, my mother and father and sister and I, hiding in the bathroom of our house (at the Amandelstraat 61 in The Hague) as the Nazi troops entered my country. We were holding wet handkerchiefs over our noses, as there had been warnings that there would be gas attacks.

The Dutch police snatched my Jewish grandparents, Gustav Lewin and Emma Lewin Gottfeld, from their house in 1942. At about the same time they hauled out my father's sister Julia, her husband Jacob (called Jenno), and her three children—Otto, Rudi, and Emmie—and put them all on trucks, with their suitcases, and sent them to Westerbork, the transshipment camp in Holland. More than a hundred thousand Jews passed through Westerbork, on their way to other camps. The Nazis quickly sent my grandparents to Auschwitz and murdered them—gassed them—the day they arrived, November 19, 1942. My grandfather was seventy-five and my grandmother sixty-nine, so they wouldn't have been candidates for labor camps. Westerbork, by contrast, was so strange; it was made to look like a resort for Jews. There were ballet performances and shops. My mother would often bake potato pancakes that she would then send by mail to our family in Westerbork.

Because my uncle Jenno was what the Dutch call "statenloos," or stateless—he had no nationality—he was able to drag his feet and stay at Westerbork with his family for fifteen months before the Nazis split up the family and shipped them to different camps. They sent my aunt Julia and my cousins Emmie and Rudi first to the women's concentration camp Ravensbrück in Germany and then to Bergen-Belsen, also in Germany, where they were imprisoned until the war ended. My aunt Julia died ten days after the camp's liberation by the Allies, but my cousins survived. My cousin Otto, the oldest, had also been sent to Ravensbrück, to the men's camp there, and near the end of the war ended up in the concentration camp in Sachsenhausen; he survived the Sachsenhausen death march in April 1945. Uncle Jenno they sent directly to Buchenwald, where they murdered him—along with more than 55,000 others.

Whenever I see a movie about the Holocaust, which I would not do for a really long time, I project it immediately onto my own family. That's why I felt the movie Life Is Beautiful was terribly difficult to watch, even objectionable. I just couldn't imagine joking about something that was so serious. I still have recurring nightmares about being chased by Nazis, and I wake up sometimes absolutely terrified. I even once in my dreams witnessed my own execution by the Nazis.

Some day I would like to take the walk, my paternal grandparents' last walk, from the train station to the gas chambers at Auschwitz. I don't know if I'll ever do it, but it seems to me like one way to memorialize them. Against such a monstrosity, maybe small gestures are all that we have. That, and our refusal to forget: I never talk about my family members having "died" in concentration camps. I always use the word murdered, so we do not let language hide the reality.

My father was Jewish but my mother was not, and as a Jew married to a non-Jewish woman, he was not immediately a target. But he became a target soon enough, in 1943. I remember that he had to wear the yellow star. Not my mother, or sister, or I, but he did. We didn't pay much attention to it, at least not at first. He had it hidden a little bit, under his clothes, which was forbidden. What was really frightening was the way he gradually accommodated to the Nazi restrictions, which just kept getting worse. First, he was not allowed on public transportation. Then, he wasn't allowed in public parks. Then he wasn't allowed in restaurants; he became persona non grata in places he had frequented for years! And the incredible thing is the ability of people to adjust.

When he could no longer take public transportation, he would say, "Well, how often do I make use of public transportation?" When he wasn't allowed in public parks anymore, he would say, "Well, how often do I go to public parks?" Then, when he could not go to a restaurant, he would say, "Well, how often do I go to restaurants?" He tried to make these awful things seem trivial, like a minor inconvenience, perhaps for his children's sake, and perhaps also for his own peace of mind. I don't know.

It's still one of the hardest things for me to talk about. Why this ability to slowly see the water rise but not recognize that it will drown you? How could they see it and not see it at the same time? That's something that I cannot cope with. Of course, in a sense it's completely understandable; perhaps that's the only way you can survive, for as long as you are able to fool yourself.

Though the Nazis made public parks off-limits to Jews, my father was allowed to walk in cemeteries. Even now, I recall many walks with him at a nearby cemetery. We fantasized about how and why family members died—sometimes four had died on the same day. I still do that nowadays when I walk in Cambridge's famous Mount Auburn Cemetery.

The most dramatic thing that happened to me growing up was that all of a sudden my father disappeared. I vividly remember the day he left. I came home from school and sensed somehow that he was gone. My mother was not home, so I asked our nanny, Lenie, "Where's Dad?" and I got an answer of some sort, meant to be reassuring, but somehow I knew that my father had left.

Bea saw him leaving, but she never told me until many years later. The four of us slept in the same bedroom for security, and at four in the morning, she saw him get up and put some clothes in a bag. Then he kissed my mother and left. My mother didn't know where he was going; that knowledge would have been very dangerous, because the Germans might have tortured her to find out where my father was and she would have told them. We now know that the Resistance hid him, and eventually we got some messages from him through the Resistance, but at the time it was absolutely terrible not knowing where he was or even if he was alive.

I was too young to understand how profoundly his absence affected my mother. My parents ran a school out of our home—which no doubt had a strong influence on my love of teaching—and she struggled to carry on without him. She had a tendency toward depression anyway, but now her husband was gone, and she worried that we children might be sent to a concentration camp. She must have been truly terrified for us because—as she told me fifty-five years later—one night she said to Bea and me that we should sleep in the kitchen, and she stuffed curtains and blankets and towels under the doors so that no air could escape. She was intending to put the gas on and let us sleep ourselves into death, but she didn't go through with it. Who can blame her for thinking of it—I know that Bea and I don't.

I was afraid a lot. And I know it sounds ridiculous, but I was the only male, so I sort of became the man of the house, even at age seven and eight. In The Hague, where we lived, there were many broken-down houses on the coast, half-destroyed by the Germans who were building bunkers on our beaches. I would go there and steal wood—I was going to say "collect," but it was stealing—from those houses so that we had some fuel for cooking and for heat.

To try to stay warm in the winters we wore this rough, scratchy, poor-quality wool. And I still cannot stand wool to this day. My skin is so sensitive that I sleep on eight-hundred-thread-count cotton sheets. That's also why I order very fine cotton shirts—ones that do not irritate my skin. My daughter Pauline tells me that if I see her wearing wool, I still turn away; such is the effect the war still has on me.

My father returned while the war was still going on, in the fall of 1944. People in my family disagree about just how this happened, but as near as I can tell it seems that my wonderful aunt Lauk, my mother's sister, was in Amsterdam one day, about 30 miles away from The Hague, and she caught sight of my father! She followed him from a distance and saw him go into a house. Later she went back and discovered that he was living with a woman.

My aunt told my mother, who at first got even more depressed and upset, but I'm told that she collected herself and took the boat to Amsterdam (trains were no longer operating), marched right up to the house, and rang the bell. Out came the woman, and my mother said, "I want to speak to my husband." The woman replied, "I am the wife of Mr. Lewin." But my mother insisted: "I want my husband." My father came to the door, and she said, "I'll give you five minutes to pack up and come back with me or else you can get a divorce and you'll never see your children again." In three minutes he came back downstairs with his things and returned with her.

In some ways it was much worse when he was back, because people knew that my father, whose name was also Walter Lewin, was a Jew. The Resistance had given him false identification papers, under the name of Jaap Horstman, and my sister and I were instructed to call him Uncle Jaap. It's a total miracle, and doesn't make any sense to Bea and me to this very day, but no one turned him in. A carpenter made a hatch in the ground floor of our house. We could lift it up and my father could go down and hide in the crawl space. Remarkably, my father managed to avoid capture.

He was probably at home eight months or so before the war ended, including the worst time of the war for us, the winter of 1944 famine, the hongerwinter. People starved to death—nearly twenty thousand died. For heat we crawled under the house and pulled out every other floor joist—the large beams that supported the ground floor—for firewood. In the hunger winter we ate tulip bulbs, and even bark. People could have turned my father in for food. The Germans would also pay money (I believe it was fifty guilders, which was about fifteen dollars at the time) for every Jew they turned in.

The Germans did come to our house one day. It turned out that they were collecting typewriters, and they looked at ours, the ones we used to teach typing, but they thought they were too old. The Germans in their own way were pretty stupid; if you're being told to collect typewriters, you don't collect Jews. It sounds like a movie, I know. But it really happened.

After all of the trauma of the war, I suppose the amazing thing is that I had a more or less normal childhood. My parents kept running their school—the Haagsch Studiehuis—which they'd done before and during the war, teaching typing, shorthand, languages, and business skills. I too was a teacher there while I was in college.

My parents patronized the arts, and I began to learn about art. I had an academically and socially wonderful time in college. I got married in 1959, started graduate school in January 1960, and my first daughter, Pauline, was born later that year. My son Emanuel (who is now called Chuck) was born two years after that, and our second daughter, Emma, came in 1965. Our second son, Jakob, was born in the United States in 1967.

When I arrived at MIT, luck was on my side; I found myself right in the middle of the explosion of discoveries going on at that time. The expertise I had to offer was perfect for Bruno Rossi's pioneering X-ray astronomy team, even though I didn't know anything about space research.

V-2 rockets had broken the bounds of the Earth's atmosphere, and a whole new vista of opportunity for discoveries had been opened up. Ironically, the V-2 had been designed by Wernher von Braun, who was a Nazi. He developed the rockets during World War II to kill Allied civilians, and they were terribly destructive. In Peenemünde and in the notorious underground Mittelwerk plant in Germany, slave laborers from concentration camps built them, and some twenty thousand died in the process. The rockets themselves killed more than seven thousand civilians, mostly in London. There was a launch site about a mile from my mother's parents' house close to The Hague. I recall a sizzling noise as the rockets were being fueled and the roaring noise at launch. In one bombing raid the Allies tried to destroy V-2 equipment, but they missed and killed five hundred Dutch civilians instead. After the war the Americans brought von Braun to the United States and he became a hero. That has always baffled me. He was a war criminal!

For fifteen years von Braun worked with the U.S. Army to build the V-2's descendants, the Redstone and Jupiter missiles, which carried nuclear warheads. In 1960 he joined NASA and directed the Marshall Space Flight Center in Alabama, where he developed the Saturn rockets that sent astronauts to the Moon. Descendants of his rockets launched the field of X-ray astronomy, so while rockets began as weapons, at least they also got used for a great deal of science. In the late 1950s and early 1960s they opened new windows on the world—no, on the universe!—giving us the chance to peek outside of the Earth's atmosphere and look around for things we couldn't see otherwise.

To discover X-rays from outer space, Rossi had played a hunch. In 1959 he went to an ex-student of his named Martin Annis, who then headed a research firm in Cambridge called American Science and Engineering, and said, "Let's just see if there are X-rays out there." The ASE team, headed by future Nobelist Riccardo Giacconi, put three Geiger-Müller counters in a rocket that they launched on June 18,

1962. It spent just six minutes above 80 kilometers (about 50 miles), to get beyond the Earth's atmosphere—a necessity, since the atmosphere absorbs X-rays.

Sure enough, they detected X-rays, and even more important, they were able to establish that the X-rays came from a source outside the solar system. It was a bombshell that changed all of astronomy. No one expected it, and no one could think of plausible reasons why they were there; no one really understood the finding. Rossi had been throwing an idea at the wall to see if it would stick. These are the kinds of hunches that make a great scientist.

I remember the exact date I arrived at MIT, January 11, 1966, because one of our kids got the mumps and we had to delay going to Boston; the KLM wouldn't let us fly, as the mumps is contagious. On my first day I met Bruno Rossi and also George Clark, who in 1964 had been the first to fly a balloon at a very high altitude—about 140,000 feet—to search for X-ray sources that emitted very high energy X-rays, the kind that could penetrate down to that altitude. George said, "If you want to join my group that would be great." I was at exactly the right place at the right time.

If you're the first to do something, you're bound to be successful, and our team made one discovery after another. George was very generous; after two years he turned the group completely over to me. To be on the cutting edge of the newest wave in astrophysics was just remarkable.

I was incredibly fortunate to find myself right in the thick of the most exciting work going on in astrophysics at that time, but the truth is that all areas of physics are amazing; all are filled with intriguing delights and are revealing astonishing new discoveries all the time. While we were finding new X-ray sources, particle physicists were finding ever more fundamental building blocks of the nucleus, solving the mystery of what holds nuclei together, discovering the W and Z bosons, which carry the "weak" nuclear interactions, and quarks and gluons, which carry the "strong" interactions.

Physics has allowed us to see far back in time, to the very edges of the universe, and to make the astonishing image known as the Hubble Ultra Deep Field, revealing what seems an infinity of galaxies. You should not finish this chapter without looking up the Ultra Deep Field online. I have friends who've made this image their screen saver!

The universe is about 13.7 billion years old. However, due to the fact that space itself has expanded enormously since the big bang, we are currently observing galaxies that were formed some 400 to 800 million years after the big bang and that are now considerably farther away than 13.7 billion light-years. Astronomers now estimate that the edge of the observable universe is about 47 billion light-years away from us in every direction. Because of the expansion of space, many faraway galaxies are currently moving away from us faster than the speed of light. This may sound shocking, even impossible, to those of you raised on the notion that, as Einstein postulated in his theory of special relativity, nothing can go faster than the speed of light. However, according to Einstein's theory of general relativity, there are no limits on the speed between two galaxies when space itself is expanding. There are good reasons why scientists now think that we are living in the golden age of cosmology—the study of the origin and evolution of the entire universe.

Physics has explained the beauty and fragility of rainbows, the existence of black holes, why the planets move the way they do, what goes on when a star explodes, why a spinning ice skater speeds up when she draws in her arms, why astronauts are weightless in space, how elements were formed in the universe, when our universe began, how a flute makes music, how we generate electricity that drives our bodies as well as our economy, and what the big bang sounded like. It has charted the smallest reaches of subatomic space and the farthest reaches of the universe.

My friend and colleague Victor Weisskopf, who was already an elder statesman when I arrived at MIT, wrote a book called The Privilege of Being a Physicist. That wonderful title captures the feelings I've had being smack in the middle of one of the most exciting periods of astronomical and astrophysical discovery since men and women started looking carefully at the night sky. The people I've worked alongside at MIT, sometimes right across the hall from me, have devised astonishingly creative and sophisticated techniques to hammer away at the most fundamental questions in all of science. And it's been my own privilege both to help extend humankind's collective knowledge of the stars and the universe and to bring several generations of young people to an appreciation and love for this magnificent field.

Ever since those early days of holding decaying isotopes in the palm of my hand, I have never ceased to be delighted by the discoveries of physics, both old and new; by its rich history and ever-moving frontiers; and by the way it has opened my eyes to unexpected wonders of the world all around me. For me physics is a way of seeing—the spectacular and the mundane, the immense and the minute—as a beautiful, thrillingly interwoven whole.

That is the way I've always tried to make physics come alive for my students. I believe it's much more important for them to remember the beauty of the discoveries than to focus on the complicated math—after all, most of them aren't going to become physicists. I have done my utmost to help them see the world in a different way; to ask questions they've never thought to ask before; to allow them to see rainbows in a way they have never seen before; and to focus on the exquisite beauty of physics, rather than on the minutiae of the mathematics. That is also the intention of this book, to help open your eyes to the remarkable ways in which physics illuminates the workings of our world and its astonishing elegance and beauty.

Most helpful customer reviews

3 of 3 people found the following review helpful.
The Second Book on Physics You Should Read
By Jesse Rorabaugh
When people decide they should learn about physics they typically do one of two things, if they are trying to teach themselves they go to a book by someone like Stephen Hawking or Brian Greene or if they are in a class they go to a book like Serway's introductory physics text. Both are a mistake. In the case of Steven Hawking or Brian Greene they will spend too much time trying to puzzle out the meaning of physics new enough it will likely be proven wrong anyways. They are likely to leave understanding little about physics but the fact that it is complicated. In the case of Serway they are likely to spend too much time doing math that while important, is likely to chase them away from physics before they have any real understanding.

This book should come before any of those. Explanations of common every day events like rainbows or pendulums with only minimal math. The only reason I say it is the second book on physics you should read is that Surely You're Joking Mr. Feynman is a better place to start. It gives little real explanation of physics but does a better job of changing your perception of physics. That book will give you enough excitement about learning physics to push you through the more complicated parts of this book then maybe even some of the more advanced texts on the subject.

3 of 3 people found the following review helpful.
Thank You Dr. Lewin for such an Incredible Gift for all of us!!!
By JK
I can't remember having so much fun, feeling so excited and learning as much as I did reading this book!! Walter Lewin's enthusiasm for physics leaps off every page. I could sense his excitement, passion and energy with every page, and I love the feel of his Dutch accent; it made the book even more intimate and engaging. However, no reader will be simply engaged, but completely and wholly sucked in and feeling like someone

just shared with you all the secrets of the universe (which Dr. Lewin actually does!). Of course you will learn a tremendous amount about physics, the world around you and the answers to a whole host of "why" questions, but I also found his enthusiasm rubbing off on me and I finished this book with a renewed sense of being more enthusiastic about life in general and vowed to look at everything with such marvel and wonder.

My 9-year old son absolutely loved this book as well. Young or old, this is a wonderful book on so many levels; taking a topic many find intimidating and making it accessible for anyone, it is Dr. Lewin speaking from the heart and sharing something truly wonderful with all of us. If you really want to see this book come alive, watch any of his lectures on MIT's website. Everyone should have a chance to experience a teacher like Dr. Lewin.

1 of 1 people found the following review helpful.
It's not a matter of understanding physics, it's a matter of falling in love with it!
By Book Shark
For the Love of Physics: From the End of the Rainbow to the Edge of Time, A Journey Through the Wonders of Physics by Walter Lewin

"For the Love of Physics" is the wonderful, educational book that enlightens the layperson to physics. Professor Lewin's passion for physics shines throughout the book as he takes readers on a journey from the tiniest particles to the utter vastness of our universe. Acclaimed MIT professor Walter Lewin, helps us see the world through the eyes of physics. This book is in essence a two-part book, in the first part Lewin focuses on the basics of physics. The second part has to do with his area of expertise, X-Ray Astronomy. An enjoyable, instructive read that is perfect for the layperson who wants to learn about physics through a practical lens versus a mathematical one. This 320-page book is composed of the following fifteen chapters: 1. From the Nucleus to Deep Space, 2. Measurements, Uncertainties, and the Stars, 3. Bodies in Motion, 4. The Magic of Drinking, 5. Over and Under, Outside and Inside, the Rainbow, 6. The Harmonies of Strings and Winds, 7. The Wonders of Electricity, 8. The Mysteries of Magnetism, 9. Energy Conservation - Plus ca change..., 10. X-rays from Outer Space!, 11. X-ray Ballooning, the Early Days, 12. Cosmic Catastrophes, Neutron Stars, and Black Holes, 13. Celestial Ballet, 14. X-ray Bursters! And. 15. Ways of Seeing.

Positives:
1. A well-written book about physics that focuses on the beauty of it rather than the details.
2. Well-researched book that is accessible to the masses.
3. Professor Lewin's goal are to educate and to exude excitement over his topics...mission accomplished. As a reader and reviewer, I appreciate the passion
4. An inside look at the world of a physicist. The love for astronomy...Interesting.
5. One of the great strengths of this book is how Lewin educates his students on physics. By using everyday experiences, he is able to convey complex topics in an understandable and hands on way.
6. There are some heart-warming and tragedy behind Professor Lewin's fascinating life and he is kind and brave enough to share them with the readers.
7. The wonderful world of optics. One of the most fascinating optical phenomena...glories.
8. Newton's three laws of motion.
9. The gravity of the situation. Mass vs. weight.
10. Does a wonderful job of properly attributing discoveries to their discoverers.
11. Answers a lot of everyday questions through physics: why is the sky blue, what causes rainbows, how do planes fly, etc....
12. The basics of sound waves. Myths debunked along the way.
13. Electricity in a whole new light. Magnetism. The physics of lightning. The great Maxwell.
14. How energy works. The various types and applications.

15. The second part of the book, the author concentrates in his area of expertise X-ray astronomy. A tour deluxe of the x-ray universe. The author goes in more depth and takes you out of the classroom. It feels like a memoir of sorts.
16. A lot of amusing tales regarding his days in the field.
17. Neutron stars, supernovae, black holes, neutrinos, pulsars..oh my!
18. Some of the most amazing facts you will ever read, "A teaspoon of neutron star matter would weigh 100 million tons on Earth".
19. X-ray bursts!
20. Stellar spectroscopy...the most powerful tool in astrophysics.
21. The golden age of cosmology.
22. Find out about Professor Lewin's "other" love.
23. Links, very helpful links that add depth to the topics discussed.

Negatives:
1. The Kindle version omits the picture inserts unless you count the links for the Kindle Fire.
2. This book is intended for the masses so those in the field of physics will find it too basic.
3. Let's face it, it pains me to say it but a lot of people just can't handle science even at its most accessible.

In summary, after reading this educational book the quote that best summarizes it, " A woman does not want to be understood, she wants to be loved". I apologize for not properly attributing the quote but I feel it captures the essence of this book. Professor Lewis wants you to learn about physics but his focus is for you to fall in love with physics. The love for physics will drive one's innate curiosity toward learning physics. It's a wonderful philosophy to have and this book emanates rays of wisdom. If you are a layperson and want to see the world in a different light by all means pick up this book!

Further suggestions: "Physics of the Future: How Science Will Shape Human Destiny and Our Daily Lives by the Year 2100" by Michio Kaku, "The Physics Book: From the Big Bang to Quantum Resurrection, 250 Milestones in the History of Physics (Sterling Milestones)" by Clifford A. Pickover, "Death from the Skies!: These Are the Ways the World Will End . . ." by Phillip C. Plait, "Death by Black Hole: And Other Cosmic Quandaries" by Neil deGrasse Tyson, "A Universe from Nothing: Why There Is Something Rather than Nothing" by Lawrence Krauss, "Knocking on Heaven's Door: How Physics and Scientific Thinking Illuminate the Universe and the Modern World" by Lisa Randall, "Wonders of the Universe" and "Why Does E=mc2? (And Why Should We Care?)" by Brian Cox, "Big Bang: The Origin of the Universe (P.S.)" by Simon Singh, and "The Grand Design" by Stephen Hawking.

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FOR THE LOVE OF PHYSICS: FROM THE END OF THE RAINBOW TO THE EDGE OF TIME - A JOURNEY THROUGH THE WONDERS OF PHYSICS BY WALTER LEWIN PDF

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Review
"MIT's Lewin is deservedly popular for his memorable physics lectures (both live and on MIT's Open Course Web site and YouTube), and this quick-paced autobiography-cum-physics intro fully captures his candor and lively teaching style...joyful...[this text] glows with energy and should please a wide range of readers."--"Publishers Weekly" (starred review)

About the Author
Walter Lewin taught the three core classes in physics at MIT for more than thirty years and made major discoveries in the area of X-ray astronomy. His physics lectures have been the subject of great acclaim, including a 60 Minutes feature, stories in the New York Times, Washington Post, Boston Globe, Newsweek and US News and World Report. They have also been top draws on YouTube and iTunes University. He was awarded three prizes for excellence in undergraduate teaching. He has published more than 450 scientific articles, and his honors and awards include the NASA Award for Exceptional Scientific Achievement, the Alexander von Humboldt Award, and a Guggenheim Fellowship. He became a corresponding member of the Royal Netherlands Academy of Arts and Sciences and Fellow of the American Physical Society in 1993. He lives in Cambridge, Massachusetts.

Warren Goldstein is a professor of history and chair of the History Department at the University of Hartford. A prizewinning historian, essayist, and journalist, he has had a lifelong fascination with physics. His writing has appeared in the New York Times, Washington Post, Boston Globe, Chicago Tribune and many other national periodicals. His prior books include Playing for Keeps: A History of Early Baseball and William Sloane Coffin, Jr.: A Holy Impatience.

For the Love of Physics CHAPTER 1

From the Nucleus to Deep Space

It’s amazing, really. My mother’s father was illiterate, a custodian. Two generations later I’m a full professor at MIT. I owe a lot to the Dutch educational system. I went to graduate school at the Delft University of Technology in the Netherlands, and killed three birds with one stone.

Right from the start, I began teaching physics. To pay for school I had to take out a loan from the Dutch government, and if I taught full time, at least twenty hours a week, each year the government would forgive one-fifth of my loan. Another advantage of teaching was that I wouldn’t have to serve in the army. The military would have been the worst, an absolute disaster for me. I’m allergic to all forms of authority—it’s just in my personality—and I knew I would have ended up mouthing off and scrubbing floors. So I taught math and physics full time, twenty-two contact hours per week, at the Libanon Lyceum in Rotterdam, to sixteen-and seventeen-year-olds. I avoided the army, did not have to pay back my loan, and was getting my PhD, all at the same time.

I also learned to teach. For me, teaching high school students, being able to change the minds of young people in a positive way, that was thrilling. I always tried to make classes interesting but also fun for the students, even though the school itself was quite strict. The classroom doors had transom windows at the top, and one of the headmasters would sometimes climb up on a chair and spy on teachers through the transom. Can you believe it?

I wasn’t caught up in the school culture, and being in graduate school, I was boiling over with enthusiasm. My goal was to impart that enthusiasm to my students, to help them see the beauty of the world all around them in a new way, to change them so that they would see the world of physics as beautiful, and would understand that physics is everywhere, that it permeates our lives. What counts, I found, is not what you cover, but what you uncover. Covering subjects in a class can be a boring exercise, and students feel it. Uncovering the laws of physics and making them see through the equations, on the other hand, demonstrates the process of discovery, with all its newness and excitement, and students love being part of it.

I got to do this also in a different way far outside the classroom. Every year the school sponsored a week-long vacation when a teacher would take the kids on a trip to a fairly remote and primitive campsite. My wife, Huibertha, and I did it once and loved it. We all cooked together and slept in tents. Then, since we were so far from city lights, we woke all the kids up in the middle of one night, gave them hot chocolate, and took them out to look at the stars. We identified constellations and planets and they got to see the Milky Way in its full glory.

I wasn’t studying or even teaching astrophysics—in fact, I was designing experiments to detect some of the smallest particles in the universe—but I’d always been fascinated by astronomy. The truth is that just about every physicist who walks the Earth has a love for astronomy. Many physicists I know built their own telescopes when they were in high school. My longtime friend and MIT colleague George Clark ground and polished a 6-inch mirror for a telescope when he was in high school. Why do physicists love astronomy so much? For one thing, many advances in physics—theories of orbital motion, for instance—have resulted from astronomical questions, observations, and theories. But also, astronomy is physics, writ large across the night sky: eclipses, comets, shooting stars, globular clusters, neutron stars, gamma-ray bursts, jets, planetary nebulae, supernovae, clusters of galaxies, black holes.

Just look up in the sky and ask yourself some obvious questions: Why is the sky blue, why are sunsets red, why are clouds white? Physics has the answers! The light of the Sun is composed of all the colors of the rainbow. But as it makes its way through the atmosphere it scatters in all directions off air molecules and very tiny dust particles (much smaller than a micron, which is 1/250,000 of an inch). This is called Rayleigh scattering. Blue light scatters the most of all colors, about five times more than red light. Thus when you look at the sky during the day in any direction*, blue dominates, which is why the sky is blue. If you look at the sky from the surface of the Moon (you may have seen pictures), the sky is not blue—it's black, like our sky at night. Why? Because the Moon has no atmosphere.

Why are sunsets red? For exactly the same reason that the sky is blue. When the Sun is at the horizon, its rays have to travel through more atmosphere, and the green, blue, and violet light get scattered the most—filtered out of the light, basically. By the time the light reaches our eyes—and the clouds above us—it's made up largely of yellow, orange, and especially red. That's why the sky sometimes almost appears to be on fire at sunset and sunrise.

Why are clouds white? The water drops in clouds are much larger than the tiny particles that make our sky blue, and when light scatters off these much larger particles, all the colors in it scatter equally. This causes the light to stay white. But if a cloud is very thick with moisture, or if it is in the shadow of another cloud, then not much light will get through, and the cloud will turn dark.

One of the demonstrations I love to do is to create a patch of "blue sky" in my classes. I turn all the lights off and aim a very bright spotlight of white light at the ceiling of the classroom near my blackboard. The spotlight is carefully shielded. Then I light a few cigarettes and hold them in the light beam. The smoke particles are small enough to produce Rayleigh scattering, and because blue light scatters the most, the students see blue smoke. I then carry this demonstration one step further. I inhale the smoke and keep it in my lungs for a minute or so—this is not always easy, but science occasionally requires sacrifices. I then let go and exhale the smoke into the light beam. The students now see white smoke—I have created a white cloud! The tiny smoke particles have grown in my lungs, as there is a lot of water vapor there. So now all the colors scatter equally, and the scattered light is white. The color change from blue light to white light is truly amazing!

With this demonstration, I'm able to answer two questions at once: Why is the sky blue, and why are clouds white? Actually, there is also a third very interesting question, having to do with the polarization of light. I'll get to this in chapter 5.

Out in the country with my students I could show them the Andromeda galaxy, the only one you can see with the naked eye, around 2.5 million light-years away (15 million trillion miles), which is next door as far as astronomical distances go. It's made up of about 200 billion stars. Imagine that—200 billion stars, and we could just make it out as a faint fuzzy patch. We also spotted lots of meteorites—most people call them shooting stars. If you were patient, you'd see one about every four or five minutes. In those days there were no satellites, but now you'd see a host of those as well. There are more than two thousand now orbiting Earth, and if you can hold your gaze for five minutes you'll almost surely see one, especially within a few hours after sunset or before sunrise, when the Sun hasn't yet set or risen on the satellite itself and sunlight still reflects off it to your eyes. The more distant the satellite, and therefore the greater the difference in time between sunset on Earth and at the satellite, the later you can see it at night. You recognize satellites because they move faster than anything else in the sky (except meteors); if it blinks, believe me, it's an airplane.

I have always especially liked to point out Mercury to people when we're stargazing. As the planet closest to the Sun, it's very difficult to see it with the naked eye. The conditions are best only about two dozen evenings and mornings a year. Mercury orbits the Sun in just eighty-eight days, which is why it was named for the fleet-footed Roman messenger god; and the reason it's so hard to see is that its orbit is so close to the Sun. It's never more than about 25 degrees away from the Sun when we look at it from Earth—that's smaller than the angle between the two hands of a watch at eleven o'clock. You can only see it shortly after sunset and before sunrise, and when it's farthest from the Sun as seen from Earth. In the United States it's always close to the horizon; you almost have to be in the countryside to see it. How wonderful it is when you actually find it!

Stargazing connects us to the vastness of the universe. If we keep staring up at the night sky, and let our eyes adjust long enough, we can see the superstructure of the farther reaches of our own Milky Way galaxy quite beautifully—some 100 billion to 200 billion stars, clustered as if woven into a diaphanous fabric, so delightfully delicate. The size of the universe is incomprehensible, but you can begin to grasp it by first considering the Milky Way.

Our current estimate is that there may be as many galaxies in the universe as there are stars in our own galaxy. In fact, whenever a telescope observes deep space, what it sees is mostly galaxies—it's impossible to distinguish single stars at truly great distances—and each contains billions of stars. Or consider the recent discovery of the single largest structure in the known universe, the Great Wall of galaxies, mapped by the Sloan Digital Sky Survey, a major project that has combined the efforts of more than three hundred astronomers and engineers and twenty-five universities and research institutions. The dedicated Sloan telescope is observing every night; it went into operation in the year 2000 and will continue till at least the year 2014. The Great Wall is more than a billion light-years long. Is your head spinning? If not, then consider that the observable universe (not the entire universe, just the part we can observe) is roughly 90 billion light-years across.

This is the power of physics; it can tell us that our observable universe is made up of some 100 billion galaxies. It can also tell us that of all the matter in our visible universe, only about 4 percent is ordinary matter, of which stars and galaxies (and you and I) are made. About 23 percent is what's called dark matter (it's invisible). We know it exists, but we don't know what it is. The remaining 73 percent, which is the bulk of the energy in our universe, is called dark energy, which is also invisible. No one has a clue what that is either. The bottom line is that we're ignorant about 96 percent of the mass/energy in our universe. Physics has explained so much, but we still have many mysteries to solve, which I find very inspiring.

Physics explores unimaginable immensity, but at the same time it can dig down into the very smallest realms, to the very bits of matter such as neutrinos, as small as a tiny fraction of a proton. That is where I was spending most of my time in my early days in the field, in the realms of the very small, measuring and mapping the release of particles and radiation from radioactive nuclei. This was nuclear physics, but not the bomb-making variety. I was studying what made matter tick at a really basic level.

You probably know that almost all the matter you can see and touch is made up of elements, such as hydrogen, oxygen, and carbon combined into molecules, and that the smallest unit of an element is an atom, made up of a nucleus and electrons. A nucleus, recall, consists of protons and neutrons. The lightest and most plentiful element in the universe, hydrogen, has one proton and one electron. But there is a form of hydrogen that has a neutron as well as a proton in its nucleus. That is an isotope of hydrogen, a different form of the same element; it's called deuterium. There's even a third isotope of hydrogen, with two neutrons joining the proton in the nucleus; that's called tritium. All isotopes of a given element have the same number of protons, but a different number of neutrons, and elements have different numbers of isotopes. There are thirteen isotopes of oxygen, for instance, and thirty-six isotopes of gold.

Now, many of these isotopes are stable—that is, they can last more or less forever. But most are unstable, which is another way of saying they're radioactive, and radioactive isotopes decay: that is to say, sooner or later they transform themselves into other elements. Some of the elements they transform into are stable, and then the radioactive decay stops, but others are unstable, and then the decay continues until a stable state is reached. Of the three isotopes of hydrogen, only one, tritium, is radioactive—it decays into a stable isotope of helium. Of the thirteen isotopes of oxygen, three are stable; of gold's thirty-six isotopes, only one is stable.

You will probably remember that we measure how quickly radioactive isotopes decay by their "half-life"—which can range from a microsecond (one-millionth of a second) to billions of years. If we say that tritium has a half-life of about twelve years, we mean that in a given sample of tritium, half of the isotopes will decay in twelve years (only one-quarter will remain after twenty-four years). Nuclear decay is one of the most important processes by which many different elements are transformed and created. It's not alchemy. In fact, during my PhD research, I was often watching radioactive gold isotopes decay into mercury rather than the other way around, as the medieval alchemists would have liked. There are, however, many isotopes of mercury, and also of platinum, that decay into gold. But only one platinum isotope and only one mercury isotope decay into stable gold, the kind you can wear on your finger.

The work was immensely exciting; I would have radioactive isotopes literally decaying in my hands. And it was very intense. The isotopes I was working with typically had half-lives of only a day or a few days. Gold-198, for instance, has a half-life of a little over two and a half days, so I had to work fast. I would drive from Delft to Amsterdam, where they used a cyclotron to make these isotopes, and rush back to the lab at Delft. There I would dissolve the isotopes in an acid to get them into liquid form, put them on very thin film, and place them into detectors.

I was trying to verify a theory about nuclear decay, one that predicted the ratio of gamma ray to electron emissions from the nuclei, and my work required precise measurements. This work had already been done for many radioactive isotopes, but some recent measurements had come out that were different from what the theory predicted. My supervisor, Professor Aaldert Wapstra, suggested I try to determine whether it was the theory or the measurements that were at fault. It was enormously satisfying, like working on a fantastically intricate puzzle. The challenge was that my measurements had to be much more precise than the ones those other researchers had come up with before me.

Electrons are so small that some say they have no effective size—they're less than a thousand-trillionth of a centimeter across—and gamma rays have a wavelength of less than a billionth of a centimeter. And yet physics had provided me with the means to detect and to count them. That's yet another thing that I love about experimental physics; it lets us "touch" the invisible.

To get the measurements I needed, I had to milk the sample as long as I could, because the more counts I had, the greater my precision would be. I'd frequently be working for something like 60 hours straight, often without sleeping. I became a little obsessed.

For an experimental physicist, precision is key in everything. The accuracy is the only thing that matters, and a measurement that doesn't also indicate its degree of accuracy is meaningless. This simple, powerful, totally fundamental idea is almost always ignored in college books about physics. Knowing degrees of accuracy is critical to so many things in our lives.

In my work with radioactive isotopes, attaining the degree of accuracy I had to achieve was very challenging, but over three or four years I got better and better at the measurements. After I improved some of the detectors, they turned out to be extremely accurate. I was confirming the theory, and publishing my results, and this work ended up being my PhD thesis. What was especially satisfying to me was that my results were rather conclusive, which doesn't happen very often. Many times in physics, and in science generally, results are not always clear-cut. I was fortunate to arrive at a firm conclusion. I had solved a puzzle and established myself as a physicist, and I had helped to chart the unknown territory of the subatomic world. I was twenty-nine years old, and I was thrilled to be making a solid contribution. Not all of us are destined to make gigantic fundamental discoveries like Newton and Einstein did, but there's an awful lot of territory that is still ripe for exploration.

I was also fortunate that at the time I got my degree, a whole new era of discovery about the nature of the universe was getting under way. Astronomers were making discoveries at an amazing pace. Some were examining the atmospheres of Mars and Venus, searching for water vapor. Some had discovered the belts of charged particles circling the Earth's magnetic field lines, which we now call the Van Allen belts. Others had discovered huge, powerful sources of radio waves known as quasars (quasi-stellar radio sources). The cosmic microwave background (CMB) radiation was discovered in 1965—the traces of the energy released by the big bang, powerful evidence for the big bang theory of the universe's origin, which had been controversial. Shortly after, in 1967, astronomers would discover a new category of stars, which came to be called pulsars.

I might have continued working in nuclear physics, as there was a great deal of discovery going on there as well. This work was mostly in the hunt for and discovery of a rapidly growing zoo of subatomic particles, most importantly those called quarks, which turned out to be the building blocks of protons and neutrons. Quarks are so odd in their range of behaviors that in order to classify them, physicists assigned them what they called flavors: up, down, strange, charm, top, and bottom. The discovery of quarks was one of those beautiful moments in science when a purely theoretical idea is confirmed. Theorists had predicted quarks, and then experimentalists managed to find them. And how exotic they were, revealing that matter was so much more complicated in its foundations than we had known. For instance, we now know that protons consist of two up quarks and one down quark, held together by the strong nuclear force, in the form of other strange particles called gluons. Some theoreticians have recently calculated that the up quark seems to have a mass of about 0.2 percent of that of a proton, while the down quark has a mass of about 0.5 percent of the mass of a proton. This was not your grandfather's nucleus anymore. The particle zoo would have been a fascinating area of research to go into, I'm sure, but by a happy accident, the skills I'd learned for measuring radiation emitted from the nucleus turned out to be extremely useful for probing the universe. In 1965, I received an invitation from Professor Bruno Rossi at MIT to work on X-ray astronomy, which was an entirely new field, really just a few years old at the time—Rossi had initiated it in 1959.

MIT was the best thing that could ever have happened to me. Rossi's work on cosmic rays was already legendary. He'd headed a department at Los Alamos during the war and pioneered in the measurements of solar wind, also called interplanetary plasma—a stream of charged particles ejected by the Sun that causes our aurora borealis and "blows" comet tails away from the Sun. Now he had the idea to search the cosmos for X-rays. It was completely exploratory work; he had no idea whether he'd find them or not.

Anything went at that time at MIT. Any idea you had, if you could convince people that it was doable, you could work on it. What a difference from the Netherlands! At Delft, there was a rigid hierarchy, and the graduate students were treated like a lower class. The professors were given keys to the front door of my building, but as a graduate student you only got a key to the door in the basement, where the bicycles were kept. Each time you entered the building you had to pick your way through the bicycle storage rooms and be reminded of the fact that you were nothing.

If you wanted to work after five o'clock you had to fill out a form, every day, by four p.m., justifying why you had to stay late, which I had to do almost all the time. The bureaucracy was a real nuisance.

The three professors in charge of my institute had reserved parking places close to the front door. One of them, my own supervisor, worked in Amsterdam and came to Delft only once a week on Tuesdays. I asked him one day, “When you are not here, would you mind if I used your parking space?” He said, “Of course not,” but then the very first day I parked there I was called on the public intercom and instructed in the strongest terms possible that I was to remove my car. Here’s another one. Since I had to go to Amsterdam to pick up my isotopes, I was allowed 25 cents for a cup of coffee, and 1.25 guilders for lunch (1.25 guilders was about one-third of a U.S. dollar at the time), but I had to submit separate receipts for each. So I asked if I could add the 25 cents to the lunch receipt and only submit one receipt for 1.50 guilders. The department chair, Professor Blaisse, wrote me a letter that stated that if I wanted to have gourmet meals I could do so—at my own expense.

So what a joy it was to get to MIT and be free from all of that; I felt reborn. Everything was done to encourage you. I got a key to the front door and could work in my office day or night just as I wanted. To me, that key to the building was like a key to everything. The head of the Physics Department offered me a faculty position six months after my arrival, in June of 1966. I accepted and I’ve never left.

Arriving at MIT was also so exhilarating because I had lived through the devastation of World War II. The Nazis had murdered half of my family, a tragedy that I haven’t really digested yet. I do talk about it sometimes, but very rarely because it’s so very difficult for me—it is more than sixty-five years ago, and it’s still overwhelming. When my sister Bea and I talk about it, we almost always cry.

I was born in 1936, and I was just four years old when the Germans attacked the Netherlands on May 10, 1940. One of my earliest memories is all of us, my mother’s parents, my mother and father and sister and I, hiding in the bathroom of our house (at the Amandelstraat 61 in The Hague) as the Nazi troops entered my country. We were holding wet handkerchiefs over our noses, as there had been warnings that there would be gas attacks.

The Dutch police snatched my Jewish grandparents, Gustav Lewin and Emma Lewin Gottfeld, from their house in 1942. At about the same time they hauled out my father’s sister Julia, her husband Jacob (called Jenno), and her three children—Otto, Rudi, and Emmie—and put them all on trucks, with their suitcases, and sent them to Westerbork, the transshipment camp in Holland. More than a hundred thousand Jews passed through Westerbork, on their way to other camps. The Nazis quickly sent my grandparents to Auschwitz and murdered them—gassed them—the day they arrived, November 19, 1942. My grandfather was seventy-five and my grandmother sixty-nine, so they wouldn’t have been candidates for labor camps. Westerbork, by contrast, was so strange; it was made to look like a resort for Jews. There were ballet performances and shops. My mother would often bake potato pancakes that she would then send by mail to our family in Westerbork.

Because my uncle Jenno was what the Dutch call “statenloos,” or stateless—he had no nationality—he was able to drag his feet and stay at Westerbork with his family for fifteen months before the Nazis split up the family and shipped them to different camps. They sent my aunt Julia and my cousins Emmie and Rudi first to the women’s concentration camp Ravensbrück in Germany and then to Bergen-Belsen, also in Germany, where they were imprisoned until the war ended. My aunt Julia died ten days after the camp’s liberation by the Allies, but my cousins survived. My cousin Otto, the oldest, had also been sent to Ravensbrück, to the men’s camp there, and near the end of the war ended up in the concentration camp in Sachsenhausen; he survived the Sachsenhausen death march in April 1945. Uncle Jenno they sent directly to Buchenwald, where they murdered him—along with more than 55,000 others.

Whenever I see a movie about the Holocaust, which I would not do for a really long time, I project it immediately onto my own family. That’s why I felt the movie Life Is Beautiful was terribly difficult to watch, even objectionable. I just couldn’t imagine joking about something that was so serious. I still have recurring nightmares about being chased by Nazis, and I wake up sometimes absolutely terrified. I even once in my dreams witnessed my own execution by the Nazis.

Some day I would like to take the walk, my paternal grandparents' last walk, from the train station to the gas chambers at Auschwitz. I don't know if I'll ever do it, but it seems to me like one way to memorialize them. Against such a monstrosity, maybe small gestures are all that we have. That, and our refusal to forget: I never talk about my family members having "died" in concentration camps. I always use the word murdered, so we do not let language hide the reality.

My father was Jewish but my mother was not, and as a Jew married to a non-Jewish woman, he was not immediately a target. But he became a target soon enough, in 1943. I remember that he had to wear the yellow star. Not my mother, or sister, or I, but he did. We didn't pay much attention to it, at least not at first. He had it hidden a little bit, under his clothes, which was forbidden. What was really frightening was the way he gradually accommodated to the Nazi restrictions, which just kept getting worse. First, he was not allowed on public transportation. Then, he wasn't allowed in public parks. Then he wasn't allowed in restaurants; he became persona non grata in places he had frequented for years! And the incredible thing is the ability of people to adjust.

When he could no longer take public transportation, he would say, "Well, how often do I make use of public transportation?" When he wasn't allowed in public parks anymore, he would say, "Well, how often do I go to public parks?" Then, when he could not go to a restaurant, he would say, "Well, how often do I go to restaurants?" He tried to make these awful things seem trivial, like a minor inconvenience, perhaps for his children's sake, and perhaps also for his own peace of mind. I don't know.

It's still one of the hardest things for me to talk about. Why this ability to slowly see the water rise but not recognize that it will drown you? How could they see it and not see it at the same time? That's something that I cannot cope with. Of course, in a sense it's completely understandable; perhaps that's the only way you can survive, for as long as you are able to fool yourself.

Though the Nazis made public parks off-limits to Jews, my father was allowed to walk in cemeteries. Even now, I recall many walks with him at a nearby cemetery. We fantasized about how and why family members died—sometimes four had died on the same day. I still do that nowadays when I walk in Cambridge's famous Mount Auburn Cemetery.

The most dramatic thing that happened to me growing up was that all of a sudden my father disappeared. I vividly remember the day he left. I came home from school and sensed somehow that he was gone. My mother was not home, so I asked our nanny, Lenie, "Where's Dad?" and I got an answer of some sort, meant to be reassuring, but somehow I knew that my father had left.

Bea saw him leaving, but she never told me until many years later. The four of us slept in the same bedroom for security, and at four in the morning, she saw him get up and put some clothes in a bag. Then he kissed my mother and left. My mother didn't know where he was going; that knowledge would have been very dangerous, because the Germans might have tortured her to find out where my father was and she would have told them. We now know that the Resistance hid him, and eventually we got some messages from him through the Resistance, but at the time it was absolutely terrible not knowing where he was or even if he was alive.

I was too young to understand how profoundly his absence affected my mother. My parents ran a school out of our home—which no doubt had a strong influence on my love of teaching—and she struggled to carry on without him. She had a tendency toward depression anyway, but now her husband was gone, and she worried that we children might be sent to a concentration camp. She must have been truly terrified for us because—as she told me fifty-five years later—one night she said to Bea and me that we should sleep in the kitchen, and she stuffed curtains and blankets and towels under the doors so that no air could escape. She was intending to put the gas on and let us sleep ourselves into death, but she didn't go through with it. Who can blame her for thinking of it—I know that Bea and I don't.

I was afraid a lot. And I know it sounds ridiculous, but I was the only male, so I sort of became the man of the house, even at age seven and eight. In The Hague, where we lived, there were many broken-down houses on the coast, half-destroyed by the Germans who were building bunkers on our beaches. I would go there and steal wood—I was going to say "collect," but it was stealing—from those houses so that we had some fuel for cooking and for heat.

To try to stay warm in the winters we wore this rough, scratchy, poor-quality wool. And I still cannot stand wool to this day. My skin is so sensitive that I sleep on eight-hundred-thread-count cotton sheets. That's also why I order very fine cotton shirts—ones that do not irritate my skin. My daughter Pauline tells me that if I see her wearing wool, I still turn away; such is the effect the war still has on me.

My father returned while the war was still going on, in the fall of 1944. People in my family disagree about just how this happened, but as near as I can tell it seems that my wonderful aunt Lauk, my mother's sister, was in Amsterdam one day, about 30 miles away from The Hague, and she caught sight of my father! She followed him from a distance and saw him go into a house. Later she went back and discovered that he was living with a woman.

My aunt told my mother, who at first got even more depressed and upset, but I'm told that she collected herself and took the boat to Amsterdam (trains were no longer operating), marched right up to the house, and rang the bell. Out came the woman, and my mother said, "I want to speak to my husband." The woman replied, "I am the wife of Mr. Lewin." But my mother insisted: "I want my husband." My father came to the door, and she said, "I'll give you five minutes to pack up and come back with me or else you can get a divorce and you'll never see your children again." In three minutes he came back downstairs with his things and returned with her.

In some ways it was much worse when he was back, because people knew that my father, whose name was also Walter Lewin, was a Jew. The Resistance had given him false identification papers, under the name of Jaap Horstman, and my sister and I were instructed to call him Uncle Jaap. It's a total miracle, and doesn't make any sense to Bea and me to this very day, but no one turned him in. A carpenter made a hatch in the ground floor of our house. We could lift it up and my father could go down and hide in the crawl space. Remarkably, my father managed to avoid capture.

He was probably at home eight months or so before the war ended, including the worst time of the war for us, the winter of 1944 famine, the hongerwinter. People starved to death—nearly twenty thousand died. For heat we crawled under the house and pulled out every other floor joist—the large beams that supported the ground floor—for firewood. In the hunger winter we ate tulip bulbs, and even bark. People could have turned my father in for food. The Germans would also pay money (I believe it was fifty guilders, which was about fifteen dollars at the time) for every Jew they turned in.

The Germans did come to our house one day. It turned out that they were collecting typewriters, and they looked at ours, the ones we used to teach typing, but they thought they were too old. The Germans in their own way were pretty stupid; if you're being told to collect typewriters, you don't collect Jews. It sounds like a movie, I know. But it really happened.

After all of the trauma of the war, I suppose the amazing thing is that I had a more or less normal childhood. My parents kept running their school—the Haagsch Studiehuis—which they'd done before and during the war, teaching typing, shorthand, languages, and business skills. I too was a teacher there while I was in college.

My parents patronized the arts, and I began to learn about art. I had an academically and socially wonderful time in college. I got married in 1959, started graduate school in January 1960, and my first daughter, Pauline, was born later that year. My son Emanuel (who is now called Chuck) was born two years after that, and our second daughter, Emma, came in 1965. Our second son, Jakob, was born in the United States in 1967.

When I arrived at MIT, luck was on my side; I found myself right in the middle of the explosion of discoveries going on at that time. The expertise I had to offer was perfect for Bruno Rossi's pioneering X-ray astronomy team, even though I didn't know anything about space research.

V-2 rockets had broken the bounds of the Earth's atmosphere, and a whole new vista of opportunity for discoveries had been opened up. Ironically, the V-2 had been designed by Wernher von Braun, who was a Nazi. He developed the rockets during World War II to kill Allied civilians, and they were terribly destructive. In Peenemünde and in the notorious underground Mittelwerk plant in Germany, slave laborers from concentration camps built them, and some twenty thousand died in the process. The rockets themselves killed more than seven thousand civilians, mostly in London. There was a launch site about a mile from my mother's parents' house close to The Hague. I recall a sizzling noise as the rockets were being fueled and the roaring noise at launch. In one bombing raid the Allies tried to destroy V-2 equipment, but they missed and killed five hundred Dutch civilians instead. After the war the Americans brought von Braun to the United States and he became a hero. That has always baffled me. He was a war criminal!

For fifteen years von Braun worked with the U.S. Army to build the V-2's descendants, the Redstone and Jupiter missiles, which carried nuclear warheads. In 1960 he joined NASA and directed the Marshall Space Flight Center in Alabama, where he developed the Saturn rockets that sent astronauts to the Moon. Descendants of his rockets launched the field of X-ray astronomy, so while rockets began as weapons, at least they also got used for a great deal of science. In the late 1950s and early 1960s they opened new windows on the world—no, on the universe!—giving us the chance to peek outside of the Earth's atmosphere and look around for things we couldn't see otherwise.

To discover X-rays from outer space, Rossi had played a hunch. In 1959 he went to an ex-student of his named Martin Annis, who then headed a research firm in Cambridge called American Science and Engineering, and said, "Let's just see if there are X-rays out there." The ASE team, headed by future Nobelist Riccardo Giacconi, put three Geiger-Müller counters in a rocket that they launched on June 18, 1962. It spent just six minutes above 80 kilometers (about 50 miles), to get beyond the Earth's atmosphere—a necessity, since the atmosphere absorbs X-rays.

Sure enough, they detected X-rays, and even more important, they were able to establish that the X-rays came from a source outside the solar system. It was a bombshell that changed all of astronomy. No one expected it, and no one could think of plausible reasons why they were there; no one really understood the finding. Rossi had been throwing an idea at the wall to see if it would stick. These are the kinds of hunches that make a great scientist.

I remember the exact date I arrived at MIT, January 11, 1966, because one of our kids got the mumps and we had to delay going to Boston; the KLM wouldn't let us fly, as the mumps is contagious. On my first day I met Bruno Rossi and also George Clark, who in 1964 had been the first to fly a balloon at a very high altitude—about 140,000 feet—to search for X-ray sources that emitted very high energy X-rays, the kind that could penetrate down to that altitude. George said, "If you want to join my group that would be great." I was at exactly the right place at the right time.

If you're the first to do something, you're bound to be successful, and our team made one discovery after another. George was very generous; after two years he turned the group completely over to me. To be on the cutting edge of the newest wave in astrophysics was just remarkable.

I was incredibly fortunate to find myself right in the thick of the most exciting work going on in astrophysics at that time, but the truth is that all areas of physics are amazing; all are filled with intriguing delights and are revealing astonishing new discoveries all the time. While we were finding new X-ray sources, particle physicists were finding ever more fundamental building blocks of the nucleus, solving the mystery of what holds nuclei together, discovering the W and Z bosons, which carry the "weak" nuclear interactions, and quarks and gluons, which carry the "strong" interactions.

Physics has allowed us to see far back in time, to the very edges of the universe, and to make the astonishing image known as the Hubble Ultra Deep Field, revealing what seems an infinity of galaxies. You should not finish this chapter without looking up the Ultra Deep Field online. I have friends who've made this image their screen saver!

The universe is about 13.7 billion years old. However, due to the fact that space itself has expanded enormously since the big bang, we are currently observing galaxies that were formed some 400 to 800 million years after the big bang and that are now considerably farther away than 13.7 billion light-years. Astronomers now estimate that the edge of the observable universe is about 47 billion light-years away from us in every direction. Because of the expansion of space, many faraway galaxies are currently moving away from us faster than the speed of light. This may sound shocking, even impossible, to those of you raised on the notion that, as Einstein postulated in his theory of special relativity, nothing can go faster than the speed of light. However, according to Einstein's theory of general relativity, there are no limits on the speed between two galaxies when space itself is expanding. There are good reasons why scientists now think that we are living in the golden age of cosmology—the study of the origin and evolution of the entire universe.

Physics has explained the beauty and fragility of rainbows, the existence of black holes, why the planets move the way they do, what goes on when a star explodes, why a spinning ice skater speeds up when she draws in her arms, why astronauts are weightless in space, how elements were formed in the universe, when our universe began, how a flute makes music, how we generate electricity that drives our bodies as well as our economy, and what the big bang sounded like. It has charted the smallest reaches of subatomic space and the farthest reaches of the universe.

My friend and colleague Victor Weisskopf, who was already an elder statesman when I arrived at MIT, wrote a book called The Privilege of Being a Physicist. That wonderful title captures the feelings I've had being smack in the middle of one of the most exciting periods of astronomical and astrophysical discovery since men and women started looking carefully at the night sky. The people I've worked alongside at MIT, sometimes right across the hall from me, have devised astonishingly creative and sophisticated techniques to hammer away at the most fundamental questions in all of science. And it's been my own privilege both to help extend humankind's collective knowledge of the stars and the universe and to bring several generations of young people to an appreciation and love for this magnificent field.

Ever since those early days of holding decaying isotopes in the palm of my hand, I have never ceased to be delighted by the discoveries of physics, both old and new; by its rich history and ever-moving frontiers; and by the way it has opened my eyes to unexpected wonders of the world all around me. For me physics is a way of seeing—the spectacular and the mundane, the immense and the minute—as a beautiful, thrillingly interwoven whole.

That is the way I’ve always tried to make physics come alive for my students. I believe it’s much more important for them to remember the beauty of the discoveries than to focus on the complicated math—after all, most of them aren’t going to become physicists. I have done my utmost to help them see the world in a different way; to ask questions they’ve never thought to ask before; to allow them to see rainbows in a way they have never seen before; and to focus on the exquisite beauty of physics, rather than on the minutiae of the mathematics. That is also the intention of this book, to help open your eyes to the remarkable ways in which physics illuminates the workings of our world and its astonishing elegance and beauty.

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