



Freeman Dyson (center) with colleagues
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Freeman Dyson remembered by people who knew him: “an unusual visionary”

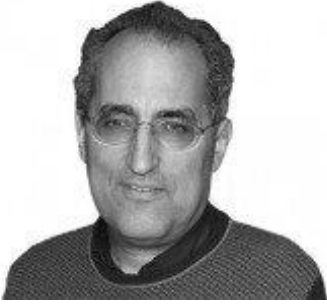
Colleagues reflect on the life and work of the renowned physicist, who died last week.

by **Edward Witten**, **Dwight Neuenschwander**, **Harold Feiveson**, **Arthur Jaffe**, and **Elliott Lieb**

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Freeman Dyson, who died on Feb 28 at the age of 96, was an intellectual giant and well-regarded as a physicist, mathematician and public intellectual—and also as a mentor, grandfather and friend. *Technology Review* asked a number of his colleagues to reflect on his life and work. These are some of the responses; more will be added in coming days.

Edward Witten, Institute for Advanced Study



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Freeman Dyson made fundamental contributions to an incredibly wide variety of fields in physics and mathematics.

Among physicists, Dyson is known most of all as one of the pioneers of quantum electrodynamics. In the 1920s, physicists had learned to describe ordinary matter via the strange and often counterintuitive theory known as quantum mechanics. Moreover, it was known that light comes in the form of individual particles, or “quanta,” known as photons. But attempts in those days to understand the quantum mechanics of light interacting with matter led to intractable difficulties.

By the late 1940s, when research in fundamental physics resumed after World War II, advances in technology made it possible to do experiments testing the quantum-mechanical interactions of photons and electrons—creating a compelling need to develop a workable theory. Dyson, along with Hans Bethe, Richard Feynman, Julian Schwinger, and Shinichiro Tomanaga, was one of the pioneers who accomplished this. Very roughly, Dyson's role was to establish a bridge between what had looked like very different and potentially incompatible approaches. In so doing, he introduced ideas and methods that are widely used today.

The theory of quantum electrodynamics that he helped establish is the prototype that was eventually elaborated into the Standard Model of particle physics.

In the 1950s, Dyson made multiple important contributions to continue developing the framework of quantum electrodynamics. This work was done at an astonishingly young age. The initial breakthroughs were made in 1948 and 1949; Dyson turned 25 in 1948. Remarkably, by this time he had already established a reputation in a completely different area: the field of mathematics known as Diophantine approximation.

The simplest version of Diophantine approximation—which goes back to the ancient Greeks, as the name suggests—is to approximate a real number such as π by rational numbers. In a more sophisticated modern version, one considers approximations by more general algebraic numbers. Dyson made a fundamental contribution in a paper published in 1947, when he was 24 years old. He retained a passion for number theory throughout his career and made multiple contributions, of which one will be mentioned shortly.

In the 1960s and afterwards, Dyson contributed extensively to quantum statistical mechanics. The general goal of this subject is to understand the quantum-mechanical behavior of an assembly of many particles—for example, the electrons and atomic nuclei in a piece of metal. In 1966, with Andrew Lenard, Dyson gave the first rigorous proof that the Pauli exclusion principle between electrons is enough to ensure that matter is stable and does not undergo spontaneous collapse. (This problem was independently analyzed by Elliott Lieb and Walter Thirring.) Dyson made many subtle contributions regarding the “phases” of quantum and sometimes classical matter, generalizing the fact that water has solid, liquid, and gas phases.

Starting in 1962, Dyson, along with Eugene Wigner and others, was largely responsible for developing what is now known as random matrix theory.

The original goal was to give a statistical description of the energy levels of atomic nuclei. Random matrix theory has developed into a major topic with far-flung applications in physics and mathematics. In physics, it is now understood as one of the basic tools in understanding quantum chaos. It has also had unexpected applications to quantum gravity. Beyond that, random matrix theory is an important tool in computer science and applied mathematics.

One of the most surprising applications arose in the 1970s, when Dyson combined his interests in number theory with his interest in random matrices and proposed that random matrix theory could describe the statistical behavior of the zeroes of the Riemann zeta function. These are central objects in number theory and the subject of the “Riemann conjecture,” one of the most celebrated unsolved problems in mathematics.

Dyson’s idea about the zeroes of the zeta function has been confirmed (and generalized to other related problems) in many different ways, ranging from theoretical proofs to computer experiments. Nowadays the link with random matrix

theory is regarded as a key clue about the Riemann conjecture, which is still unresolved.

In short, Freeman Dyson left his mark in numerous areas of physics and mathematics. His contributions were so wide-ranging that it is virtually impossible for any one person to summarize them adequately.

Dwight Neuenschwander, Southern Nazarene University

At the reception before Professor Dyson gave a speech accepting the Templeton Prize in 2000, a long line of distinguished people were waiting to shake hands with him and his wife, Imme. I was standing off to the side, watching. Suddenly his grandchildren burst through the door, ages toddler to about 6. They ignored the line of dignitaries and ran toward Freeman shouting, “Papa! Papa!” The next few seconds were touching. Professor Dyson turned from the line of dignitaries and got down on his knees, and those kiddos swarmed all over him. The people waiting in line had to wait. But they did not seem to mind—we all had the privilege of watching a precious moment in the lives of half a dozen grandchildren and their beloved grandfather.

“These days I spend more time babysitting and less time writing books. You never know which job will turn out to be most important!”

By that time I had been corresponding with him for years. In 1993, together with some students, I had written a letter to him with some questions and comments about his book “Disturbing the Universe”, hoping for a brief response. He wrote back at length a few days later, which was the beginning of a correspondence that would last for decades.

Incidentally (or not; it’s characteristic of him), after he received the Templeton Award he used some of the award funds to endow a scholarship at my university, so students could travel to our field station, the Quetzal Education Research Center in the Talamanca Mountains cloud forest of Costa Rica. It was always a financial struggle for students to go there to take courses and do research, but for several years now we have had the Freeman Dyson Travel Scholarship.

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SCHOOL OF NATURAL SCIENCES

February 21 1995

Dear Dr. Neuenchwander

What a delight to hear from you again, and this time with such a heart-warming collection of accolades from your students! Please thank the students, and yourself, for the beautiful Monet lily-pond and the messages inside it. It means a great deal to me to receive a ~~rep~~ response like this from a new generation of young people. I wish every one of the students as challenging and rewarding a life as I have been blessed with.

Now I am a busy grandfather with our three little grandsons living here in Princeton (ages 3, 1, 1). Lucky again! On Sunday we took all three of them to church and they loved it. As I grow older, I spend more time baby-sitting and less time writing books. You never know which job will turn out to be more important! Please keep in touch!

Yours ever
Freeman Dyson.

Jump ahead to 2012, when the physics honor society Sigma Pi Sigma held its quadrennial meeting or “congress” in Orlando. About 800 people attended that meeting; some 600 of them were undergraduate physics students. Professor Dyson was a featured plenary speaker, scheduled to speak on Saturday morning. The conference began on Thursday evening. That evening, quite unexpectedly, I walked Professor Dyson, straight from the airport, holding his briefcase. He was immediately surrounded with the spontaneous reception one might envision for a member of a royal family who also happens to be a rock star.

For the rest of the meeting, during any break, a very long line immediately formed before Professor Dyson. Everyone wanted to shake his hand, have him sign a book, or get a photo made with him. He patiently talked to each and every individual. On Saturday morning he joined the students in the roundtable breakout groups. When the meeting broke up on Saturday night, I was helping the staff take down the registration booth at 10 p.m. The convention center was deserted except for a few stragglers. Those stragglers were students who were still having conversations with Professor Dyson. Other than the meeting staff and convention center personnel, he was literally the last one to leave the meeting. He did not leave until everyone who wanted to talk with him had done so. Of course, he was much younger then—a mere 89!

In a hand-written letter to my class, he described spending time with his daughter’s children, saying, “These days I spend more time babysitting and less time writing books. You never know which job will turn out to be more important!” I have thought about that a lot over the years as I have tried to balance the sometimes orthogonal demands of raising children and building a career.

My students asked a lot about science and religion. In his very last letter to us of December 10, 2019, in response to our question about the “optimal relationship between doubt and faith,” he replied, “The optimum relationship between doubt and faith is peaceful coexistence. Both are essential to the evolution of a creative human society. Faith to pursue impossible goals, doubt to recover from disastrous mistakes. We have to learn to tolerate a wide variety of faiths and doubts.”

Professor Dyson was more to me than the author of a beloved textbook. He was an inspiration and he became a friend. I am so blessed that my path crossed his. And I speak for over 3,000 students who feel the same way, who over the past 25 years have come to meet him and share his wisdom through his books and letters.

Harold Feiveson, Princeton University

The last time I saw Freeman was three weeks ago, when he came to a talk I was giving at Princeton on the role of scientists in World War II. Freeman was of course one of those scientists, working in the operations research group of the Royal Air Force. I started my talk by observing that in early 1942, with the Nazis controlling all of Europe except Great Britain and the Japanese ascendant everywhere, few would have been confident that the Allies would prevail. Freeman immediately disagreed, with his impish sense of humor. No, he said—once the Germans had invaded the Soviet Union, he was confident that the Allies would win the war. I drove Freeman home that day and his mind was as sharp as ever, though he was not so sure of his body.

That was three weeks ago. But I think back over 50 years ago, when I first heard of Freeman. In 1963 I joined the Science Bureau of the US Arms Control and Disarmament Agency, an agency newly created by the Kennedy administration. I was shown a study that Freeman had done during the summer of 1962 for the agency, “Implications of New Weapons Systems for Strategic Policy and Disarmament.”

It was quite a study, with several intriguing thoughts on possible future technical developments such as low-yield nuclear weapons and laser anti-missile systems. What was more interesting, however, was the first intimation of themes that Freeman subsequently stated with even greater force: that nuclear weapons are immoral and not very useful, and should be gotten rid of; that anti-missile defensive systems are not necessarily bad; and that disarmament could come about in ways not then imagined.

To provide warmth and air, trees would be grown on the comets, and because of the comets’ low gravity, the trees could reach heights of a hundred miles!

On this last point, Freeman subsequently brought to our attention the book *The Camel and the Wheel*, by Richard Bulliet, a historian of early Arab civilization. As Bulliet argued, the technology of wheeled transport, well known in the Middle East in Roman times, began to disappear around 500 A.D., as caravans of camels took over the transportation business. Roads soon fell into disrepair; the skills needed to build and repair wheeled carts were forgotten. Within a couple of generations, wheeled vehicles vanished throughout the Arab territories. Even the memory of their existence disappeared from the Arab world. Freeman noted that if nuclear weapons are to disappear, it is likely they will follow a similar path, gradually falling into irrelevance because no one will have use for them.

I didn't really get to know Freeman until I got to Princeton in 1967, when I was introduced to him as an environmentalist. In 1972, my colleague Robert Socolow and I organized a colloquium series with the title "On Wilderness." Freeman's talk in this series, "Outer Space: A Final Wilderness," was striking. In this talk, Freeman dismissed the asteroids or planets as fit places for colonization and wilderness adventure, but speculated instead about comets, which have abundant water, nitrogen, and carbon. To provide warmth and air, trees would be grown on the comets, and because of the comets' low gravity, the trees could reach heights of a hundred miles! Freeman read from the diaries of Governor William Bradford to show how enormously we have underestimated the human and economic costs of the Mayflower colony, including the costs to the indigenous people. In many respects these costs, argued Freeman, are comparable to and perhaps greater than those that we would face in the next century in setting out to establish a space colony. Already in Freeman's talk were several themes which he later made much more of. I will mention three.

Quick is beautiful. If new kinds of industrial processes, transportation systems, energy technologies, and so forth take more than a short time to produce, they are probably a bad idea; it takes too long to find mistakes and fix them. (This does not mean that Freeman looked with favor only at small technologies; he participated in Project Orion, Ted Taylor's project to build nuclear-explosion-propelled space ships!)

Technology is unpredictable. Because of unpredictability, we want to remain flexible enough to change if we have to because of unforeseen environmental impacts. To elaborate on this point, Freeman drew on the work of Lynn White, whose paper "Technology Assessment from the Stance of a Medieval Historian" showed how impossible it would have been to do a "technology assessment" of most of the technologies developed in the Middle Ages—such as eyeglasses, the distillation of brandy, the crossbow, knitting, the spinning wheel, buttons, and the fireplace. For example, by increasing privacy, the chimney and fireplace may have (in White's view and the words of L.J. Dresbeck) "affected the art of love more than the troubadours did."

Diversity is to be praised. Freeman's praise of diversity goes deep into many fields of human endeavor, but for the environment it is mainly, I think, a plea for scientists and others not to all work on the same problem, but rather to tackle a whole range of issues.

All this led Freeman to be a strong advocate for renewable energy despite his well-known skepticism of many of the computer models of global warming. Freeman

believed that renewable energy technologies, by virtue of their scale and technological simplicity in the field, and by virtue of the fact that almost all developing countries are rich in sun, wind, and biomass, might at last allow people to shape energy to the real needs of people, including the rural poor in developing countries. On the subject of global warming, I should also mention Freeman's strong advocacy of growing biomass on a very large scale to take carbon out of the atmosphere.

As he would say of himself, Freeman was obsessed about the future. He thought of how our actions today will impact future generations, and he was, in almost a religious sense, optimistic about that future.

Arthur Jaffe, Harvard University



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I first met Freeman Dyson when I was a graduate student at Princeton almost 60 years ago. He already had a towering reputation, and was something of an enigma to my generation of students.

I recall that Dyson began his course on quantum theory by telling us, "If anyone tells you that they understand quantum theory, they are not telling the truth." We were fascinated by his lectures, and so I invited him with a small group of friends for dinner. I remember him warning us that the biggest change in our lives would result from the economic development of China. This was a scenario that few people were prepared to believe would change the world to the extent that it has. No one predicted at that time how China's economic emergence, and the accompanying government prioritization of education and research, would lead to the overwhelming pool of extraordinarily talented young Chinese mathematicians and physicists that we have today.

My teacher Arthur Wightman had enormous respect for Dyson, and he often pointed to Dyson's many accomplishments in quantum field theory and many-body quantum

systems, including the Dyson series, the Dyson representation, his work on stability of quantum matter, etc. Wightman also said that Dyson's first draft of a paper would generally be its last draft, as he could formulate his ideas and words so coherently before setting them on paper. Furthermore, he reported that Dyson was a voracious reader; each day he could recount at lunch the new developments he read in the preprints that had just arrived in the mail.

I have long been fascinated by two of Dyson's essays. In his 1972 Gibbs lecture to the American Mathematical Society, entitled "Missed Opportunities," Dyson wrote:

I happen to be a physicist who started life as a mathematician. As a working physicist, I am acutely aware of the fact that the marriage between mathematics and physics, which was so enormously fruitful in past centuries, has recently ended in divorce.

The divorce for a time was so complete that Dyson remembered staring at a sequence of numbers that he thought in retrospect should have seemed familiar: 3, 8, 10, 14, 15, 21, 24, 26, 28, 35, 36, ... He wrote:

As I was, for the time being, a number theorist, they made no sense to me. My mind was so well compartmentalized that I did not remember that I had met these same numbers many times in my life as a physicist ... the number theorist Dyson and the physicist Dyson were not speaking to each other.

As a result, Dyson missed out on discovering a fundamental connection between two different mathematical objects called Lie algebras and modular forms. Thankfully physics and mathematics have had a reconciliation, so some scholars like Dyson are once again respected both as mathematicians and as physicists.

In his 2009 essay "Birds and Frogs," Dyson compared two approaches to discovery in mathematics by likening them to those creatures:

Birds fly high in the air and survey broad vistas of mathematics out to the far horizon. They delight in concepts that unify our thinking and bring together diverse problems from different parts of the landscape. Frogs live in the mud below and see only the flowers that grow nearby. They delight in the details of particular objects, and they solve problems one at a time. I happen to be a frog, but many of my best friends are birds ... Mathematics needs both birds and frogs.

We will miss Dyson not only as a friend but as an unusual visionary, unafraid to challenge conventional thought whenever and wherever he could.

Elliott Lieb, Princeton University



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To talk about Freeman's career is like being put in the position of the blind Jain monks who were asked to describe an elephant. His scientific work covers so many areas in such depth that few, if any can comprehend more than parts of it. If we look at the non-scientific, political, literary, and unpublished governmental work as well, then it is altogether an elephant with at least six legs and maybe two trunks.

However, Freeman might not wish to be compared to an elephant—although it has to be said that he is on record as once referring to himself as a frog scientist who likes to play in the local mud instead of a bird scientist who pretends to an exalted view. In fact, he was both. Be that as it may, an elephant won't do.

At one point I had the pleasure of walking in a tropical rain forest and hit on the right metaphor for Freeman, one that more appropriately captures his activities. In the forest one can find tremendously huge trees, each supporting all kinds of ecosystems clinging to it at various heights. Freeman is like such a giant tree standing in the middle of the statistical mechanics forest. Many of the topics we work on would not be alive if Freeman had not started an enterprise that grew into a cluster of activity centered around his original insight. An example is "Dyson dynamics," invented in 1962, whose relevance to random matrix theory was recently discovered and led to a major breakthrough. Moreover, these activities retain their vitality, which is more than can be said for some of the fads that occasionally mark the progress of theoretical physics.

His career, which started in high school, was at first in pure mathematics, specifically number theory. He describes this aspect of his work as applied mathematics—the

reason being that pure mathematics is concerned with the invention of new mathematical ideas and not with the solution of old problems. As is well known, he never bothered to get a PhD, which fits him well, but there are few people like him who can have a stellar scientific career without passing through the rites set by the profession.

The original proof of the quantum-mechanical stability of matter by Dyson and Andrew Lenard in 1967 certainly must be counted as one of the most advanced pieces of hard mathematical analysis up to that time. It had two outstanding Dyson hallmarks. One was the ability to recognize a core problem in physics—even though the received wisdom at the time was that there was nothing interesting here. The other is the ability to create the mathematics necessary to crack the problem.

Since that time mathematical physics has come a long way, and we are not surprised to see occasional breakthroughs, with newly invented bulldozers clearing paths through the forest. But that kind of performance had not been seen previously.

Many of the topics we work on would not be alive if Freeman had not started an enterprise that grew into a cluster of activity centered around his original insight.

Having cited these aspects of Freeman's contributions, we must come back to the epicenter of his dynamic life. Freeman described himself as an expert in mathematical physics, which he characterized as "a discipline of people who try to reach a deep understanding of physical phenomena by following the rigorous style and method of mathematics." He continued, "It is a discipline that lies at the border between physics and mathematics. The purpose of mathematical physicists is not to calculate phenomena quantitatively but to understand them qualitatively. They work with theorems and proofs, not with numbers and computers. Their aim is to qualify with mathematical precision the concepts upon which physical theories are built."

Let me end by indulging in a few personal reminiscences about my own indebtedness to Freeman. My first interaction with him was as a graduate student in the 1950s. There was essentially no book available to learn the modern quantum field theory from, except for Freeman's book *Advanced Quantum Mechanics*. These course notes have been recently republished and are available online. He wrote it in 1951, when he was 28 years old. How many people can write a leading-edge book at that age? I tried to understand it and didn't really do so until I was 38, but that didn't stop me from writing a PhD thesis on the topic in 1956!

Freeman's positive 1967 review in *Physics Today* of my book with Dan Mattis on one-dimensional physics helped us a lot, but the point for the moment is that it showed, once again, his interest in the crazy ideas and his willingness to go to bat for them. He wrote, and I quote, "A man grows stale if he works all the time on insoluble problems, and a trip to the beautiful world of one dimension will refresh his imagination better than a dose of LSD."

Portions of Elliott Lieb's essay previously appeared in articles in [Communications in Mathematical Physics](#) and [Worlds Scientific](#) celebrating Freeman Dyson's 80th and 90th birthdays, and are used here with permission.