
CALTECH

A Celebration of Willy Fowler

"Some people are ageless and Willy was one of them. His creative mind, wit, and exuberant personality never dimmed or clouded."

At the December "Celebration," Robert Christy (left), a long-time colleague of Fowler's, likened him to a locomotive. Some of Fowler's collection of model locomotives adorned the stage in Beckman Auditorium (below).

The late William A. Fowler, Nobel laureate and Institute Professor of Physics, Emeritus, had participated in more than half of Caltech's history. He arrived on campus in 1933 as a graduate student under Charles Lauritsen in Kellogg Radiation Laboratory, earned his PhD in 1936, stayed on as a faculty member, and essentially never left. He won the Nobel Prize in 1983 for describing the succession of complex nuclear reaction processes by which elements are synthesized during the evolution of stars.

When Fowler died on March 14, 1995, at the age of 83, his colleagues and friends decided that no ordinary memorial would suffice. So, for three days in December, a symposium on nuclear astrophysics (subtitled "A Celebration of Willy Fowler") was held on the Caltech campus. "The idea was to have a celebration for what has been contributed," said G. J. Wasserburg, Crafoord laureate and the John D. MacArthur Professor of Geology and Geophysics, who chaired the program committee. "The celebration was to exhibit the vitality of the field, which is the real inheritance of Willy Fowler." The symposium included sessions on the early universe, experimental nuclear astrophysics, the neutrino, stellar nucleosynthesis, chemical evolution of the galaxy, formation of stars from the interstellar medium, presolar stellar dust grains in meteorites, and gamma ray astronomy.

Also part of the celebration was a more customary memorial observance, which attracted a large audience of Fowler's friends and admirers to Beckman Auditorium on the afternoon of December 14. Before introducing the other speakers, Wasserburg read a poem by John Donne, "The Will," which included the lines:

> To him for whom the passing bell next tolls,
> I give my physick bookes; my writen rowles
> Of Morall counsels, I to Bedlam give;
> My brazen medals, unto them which live
> In want of bread; To them which passe among
> All forrainers, mine English tongue.
>
> . . . . . .
>
> Therefore I'll give no more; But I'll undoe
> The world by dying; because love dies too.
> Then all your beauties will be no more worth
> Than gold in Mines, which none doth draw it forth;
> And all your graces no more use shall have
> Than a Sun dyall in a grave.

"Willy was a big fan of the English," Wasserburg explained. "It was even rumored that Willy liked English food. And he loved Cambridge and Oxford. Donne was at Oxford in the 1580s and reportedly went from Oxford to Cambridge to improve his character. Willy did this also, but I don't think much improvement was either necessary or possible at that time."

Wasserburg also read parts of letters from John H. Gibbons and Fred Hoyle, who were unable to attend the memorial. Gibbons, science adviser to President Clinton, wrote that, "some people are ageless and Willy was one of them. His creative mind, wit, and exuberant personality never dimmed or clouded." Gibbons noted the seminal 1957 paper by Burbidge, Burbidge, Fowler, and Hoyle (whichWasserburg always called "Burble, Burble, Toil, and Trouble") and the influence it had on his own work at Oak

Left: B²FH (in order, left to right) at the Institute of Theoretical Astronomy in Cambridge, England, on the occasion of Fowler's 60th birthday in 1971. The locomotive (also seen on the previous page) was a present from his Cambridge friends on this occasion.

Ridge National Laboratory. "Willy was himself a kind of bright star, a supernova in my book," wrote Gibbons. "He was particularly pleased when we included a quote from Walt Whitman in one of our papers: 'I believe that a leaf of grass is no less than the churning work of the stars.' Now Willy belongs to the stars."

In his letter Fred Hoyle evoked the many memories that had come crowding in when he started to write—the high points of his scientific work with Fowler, "events one would greatly wish to relive if that were possible." One event in particular that he remembered well was the Moscow International Atomic Union in 1958, in which "protocol in 1958, as you can jolly well imagine, was very difficult. There was a long lunch with lots of vodka, and the person who carried the ball that day was Willy, who could belt vodka down and keep up the good humor with our Soviet compatriots."

Wasserburg then introduced the speakers who were there in person.

Margaret Burbidge wearing a "gorgeous shiner" ("Willy would have loved it") with G. J. Wasserburg at the memorial observance.

Margaret Burbidge
Professor of Physics
University of California at San Diego

{Burbidge, who appeared wearing a black eye and a head scarf where her scalp had been stitched up, explained that she had hit the edge of a door while running to pick up a computer printout. "Willy would have loved it," she said. "He'd have been sorry for me and sympathized with all his heart, but he would have made a joke of it and so I make a joke of it." She then read from an excerpt of an autobiographical article entitled "Watcher of the Skies," which she had written for the 1994 volume of the Annual Reviews of Astronomy and Astrophysics.*}*

"It was in the autumn of 1954 that Geoff and I made the acquaintance of Willy Fowler and his family. He was spending a sabbatical year at the Cavendish, where he had hoped to do some experimental nuclear physics but had found that none of the equipment he needed was available or working. At this time element abundances were emerging from our curve of growth analysis of [a particular star with a strong magnetic field], and the heavy element anomalies were beginning to suggest that somehow neutrons were involved, an idea whose germ had been planted by work which we had heard two years earlier in a talk given by Maria Mayer and a talk given a year later by Gamow about primordial nucleosynthesis. But we believed the processes must take place in stars. While we were well educated in atomic physics, we knew much less about nuclear physics. Geoff attended a meeting of a scientific society in Cambridge, England, and listened to a lecture given by Willy Fowler, and after the lecture, Geoff asked him if we could talk to him about processes involving neutrons in stars.

"Fowler, a leader in the experimental nuclear physics program at Kellogg on the light elements, had recently worked with Salpeter and Hoyle while they were visiting Caltech. He was excited by the prospect of adding neutron processes towards a theory to build all the elements

Right: Spruce Schoenemann (age 7) and his grandfather rest atop Haystack Mountain in Vermont after a hike in June 1988.

in their cosmic abundances through generations of stars, which through evolution, finally produced [the elements around iron in the periodic table of elements], and then supernovae exploding and enriching the interstellar medium with heavy elements made from the initial ingredient, hydrogen. Fred Hoyle was in Cambridge, and we four worked together during that exciting 1954–55 year, adding together one piece after another of the puzzle. Willy's wife, Ardy Fowler, in her wonderful hospitable way made available their rented home in Cambridge, and we four divided time between there, the Cavendish Laboratory, and Botolph Lane, which was where Geoff and I had a flat, until the time came when Geoff and I had to think about jobs for next year. . . . We set off for Pasadena while the work on B^2FH was only partly completed, the primary goal to spend most of the next two years on that major project."

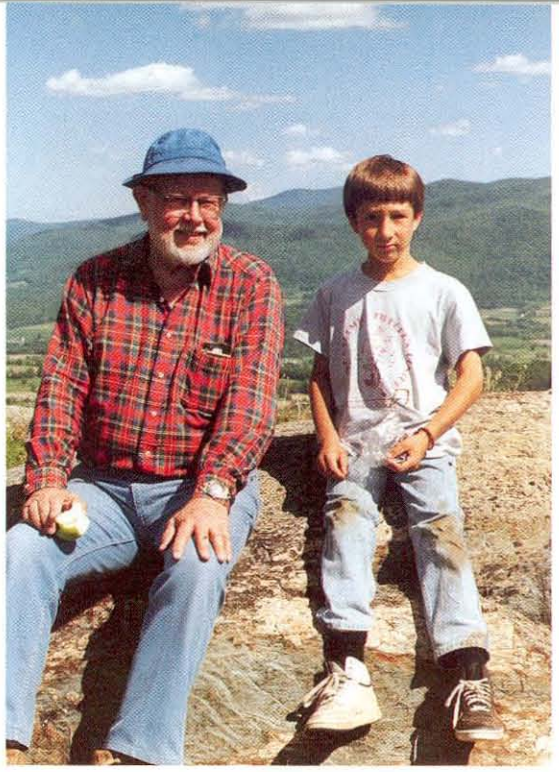
{Skipping to another passage in her article, Burbidge described the experimental work that Fowler and the Lauritsens organized at Kellogg Lab, which was crucial to the calculation of the synthesis of the light elements.}

"B^2FH brought me some of the happiest and most productive times in my scientific life. It was such fun working with you and Geoff and Fred that I really do not know what brought the tears."

When I sent Willy a reprint of this article, he wrote me a wonderful letter in November 1994, which must have been among the last letters that he wrote:

> "Dear Margaret,
>
> Nothing in recent years has given me such pleasure as reading 'Watcher of the Skies.' Actually, at some times tears came to my eyes. B^2FH brought me some of the happiest and most productive times in my scientific life. It was such fun working with you and Geoff and Fred that I really do not know what brought the tears. Thank you for bringing back those wonderful times."

Being here brings back all the memories of the two years we spent at Caltech and the summers that we spent subsequent to that. During those two years we lived in a house on South Chester, and I think that, from Beckman Auditorium I can see one or two of the trees that used to grow in our backyard.



Spruce William Schoenemann
Pawlet, Vermont

My grandfather spent a lot of time with me when I was a child, even though we lived far apart. Up until the last two or three years, Willy and I shared many physical activities. On my numerous visits to California, we kicked the soccer ball around or tossed the football at the Caltech soccer field. As a family we took hikes in the Angeles Crest, which I enjoyed immensely. I know Willy enjoyed those excursions too. On Willy's visits to Vermont we would sometimes go on hikes up Haystack Mountain, take walks through the beautiful Vermont countryside or pick apples. In the summer of 1988 my grandfather helped build a treehouse for me. I think what he enjoyed most about it was the supervising part. He told my father how things should be done or he would tell me to hand him a tool, depending on what he was doing.

Willy loved telling people things, especially the plentiful stories of his experiences. Many evenings were spent listening to his adventures in the South Pacific, his work in Los Alamos, or his train trips through Russia. He delighted in telling people of his reminiscences. Willy was quite a talker.

One of Willy's fond memories was working at Caltech throughout most of his life. He told me about the work he was doing at the Institute and once in a while he would bring me to his office or lab. I could tell by his exuberance when he spoke of Caltech that he loved the school greatly. He enjoyed his work, his colleagues, and his stu-

dents. I am sure all of you can remember Willy's extreme fondness for Caltech and the joy he got from telling his stories and jokes.

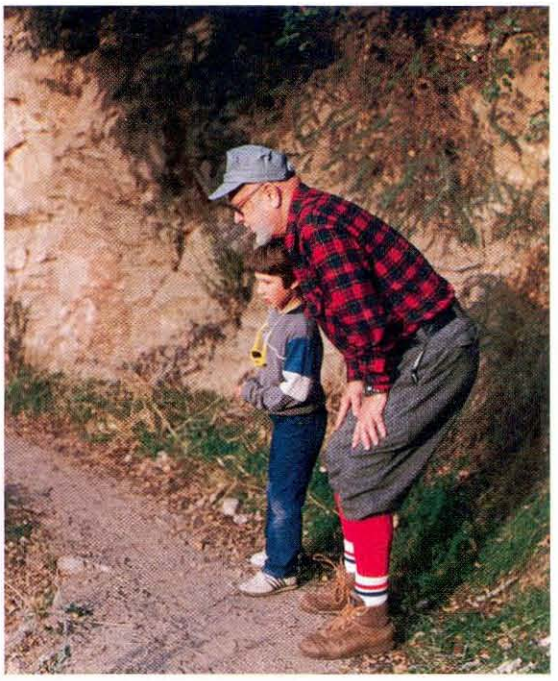
One story that Willy told me about was his disregard for the label "expert." He was very skeptical of experts, especially self-appointed ones, as he said. He once sprained his wrist while traveling on the East Coast. He went to a doctor recommended by a friend, and found through x-rays that the wrist was not broken. When Willy walked out of the doctor's office, the doctor directed him to bathe the wrist in hot water three times a day. Willy explained, "Doctor, what do you mean? My mother always told me to bathe a sprain in ice water." "Well, your mother was wrong," the doctor replied. "*My* mother told me to use hot water." So much for titles and degrees.

However, Willy did become an expert in his own field, and it is interesting to me that even as a teenager he recognized some importance of his being here in this world. I know this because Mary Dutcher Fowler found a short autobiography Willy had written as a senior at Lima Center High School. She unearthed it this past summer from the piles of papers and books on the floor of Willy's study.

In the first chapter he relates a strange event that occurred on the day he was born. A lone owl, perched in an oak tree outside the room in which he and his mother slept, shrieked in a weird and terrifying way all through the night. In the following words Willy questions the significance of this event: "All of us have a touch of the superstitious in us. I would not be human if I did not think deep in my mind that the cry of the screech owl meant something. But what that something was has never occurred to me—whether the owl was prophesying, warning, or neither. Nevertheless, I feel at least my birth transcended the commonplace." While Willy was unable or unwilling to identify this herald, to me the owl's screech and its presence meant one thing: owls are known for being wise and retaining immense amounts of knowledge. I think the owl's screech was symbolic of Willy's gift of wisdom and knowledge.

{Spruce read a few more excerpts from Fowler's teenage autobiography—about his "golden childhood" as a typical American boy who liked to play baseball and who was looking forward eagerly to the rest of his education. The essay concluded: "I sincerely want to live a life that shall not have been in vain."}

How prophetic his autobiography seems. Although the young Willy could not know it, his life certainly became extraordinary.



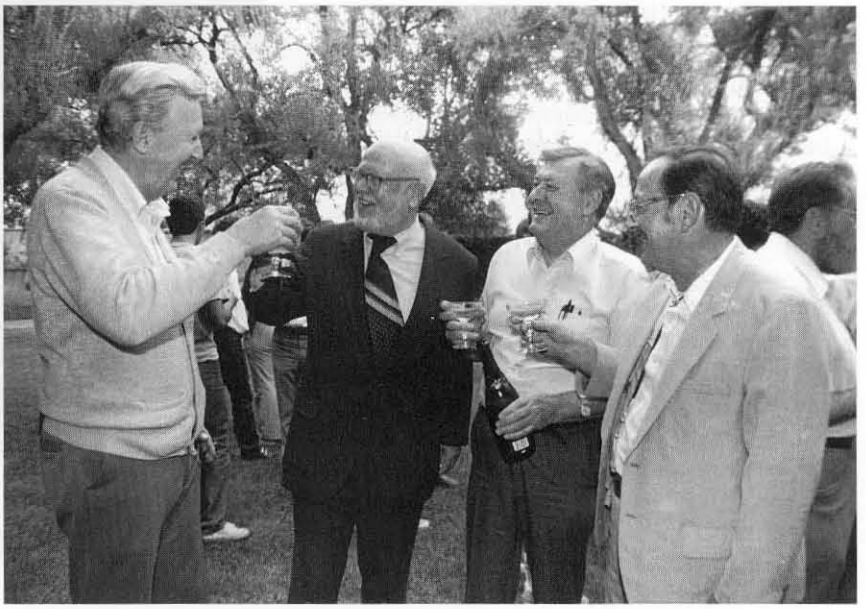
Willy and Spruce (age 6) in the San Gabriel Mountains above Pasadena on another hike (right), and in Vermont for Fowler's 83rd birthday in August 1994 (below). It was Fowler's last visit to Vermont before becoming bedridden in November.

In a talk prepared for the 1988 Caltech graduation exercises, Willy noted his dissatisfaction with the term "commencement." He preferred to call it "completion." Today we celebrate his life and recognize the completion of his physical life. But my grandfather will live on in my mind, my heart, and my fond memories, as well as yours, and in his contributions to the world of science. In spirit Willy and I will be sharing many more hikes, side by side.

Robert Christy
Institute Professor of Theoretical Physics, Emeritus
Caltech

I have many fond memories of Willy, and I would like to share some of them with you. He was a real leader, which I assume came naturally to him; in any case, he did it well. In 1951 Caltech was asked to run a study project, Project Vista, on the defense of Western Europe. Many of us contributed in our areas of expertise, but Willy was chosen to be the director. He ran it and he ran it well. Also, as many of you know, Willy ran a considerable research group and ran it well for many years. It is fitting that he had a passion for steam locomotives. In a way, he himself was a locomotive, a prime mover. Now, although Willy was the powerful force pulling in front in many cases, Charlie Lauritsen was sometimes the one with his hand on the throttle.

Willy helped the careers of his students, postdocs, and colleagues. He recommended them for positions, for promotions, and for honors. I



Above: At Tommy Lauritsen's house in the 1950s, a then-beardless Fowler (center) joins the chorus with Volney Rasmussen (left) and Lauritsen, while Victor Weisskopf accompanies. Right: Long-term Kellogg collaborators Ralph Kavanagh (left) and Charles Barnes (second from right) toast Fowler's Nobel Prize in October 1983, along with G. J. Wasserburg (right), whose work was strongly identified with the Kellogg group.

expect that many of you, like myself, are indebted to Willy. I came to Caltech as a result of a phone call from him, and such honors as I have received I suspect were helped by a good word from Willy.

I remember the strong sense of fun that marked him. He was in the best sense of the word the life of the party, and I remember well his leading the singing at the Kellogg parties. I also remember the hat and mirror trick he liked to do, in which he wore a hat next to a mirror and someone in front would blow at a glancing angle, and Willy's hat would hover a few inches above his head and then settle down. He also loved to dance, and I'm told he was very good.

He was a strong supporter of his favorite teams—the Pittsburgh Pirates and, in football, Ohio State, which he had attended as an undergraduate. He and Bob Bacher, who was a Michigan alumnus, always had a bet on the Ohio State-Michigan game, and I can imagine Willy turning over in his grave at the result of that game this fall.

Having known Willy, and having worked and played with him, will always mean a lot to me. He was a major force in my own life, and, like most of you, I miss him.

Charles Barnes
Professor of Physics, Emeritus
Caltech

I can't imagine any group of young physicists who had a better time in their careers than those who were fortunate enough to have worked with Willy Fowler. He, and Charlie and Tommy Lauritsen, worked hard themselves and inspired everyone around them to do the same. The excitement of the search for new understanding made it all something that we loved to do. After their pioneering nuclear physics work with an old and primitive accelerator through the 1930s, the Kellogg Lab physicists were fascinated by Hans Bethe's and Carl von Weizsäcker's proposals for two alternative ways that four hydrogen nuclei might fuse together to make a helium nucleus and, at the same time, produce the prodigious energy output of a star for millions, or even billions, of years, depending on the mass of the star. Willy and his colleagues proceeded to build a new and much improved accelerator to study the feasibility of these theoretical proposals, but their efforts were interrupted in 1940 by urgent national defense work.

After the war, Willy and his students resumed their study, and by 1954 they had shown that both mechanisms were indeed feasible processes for fusing hydrogen to helium in stars and, surprisingly, that our sun functioned on the chain of reactions that had been considered as the less favorable one in the theoretical work. After this work on the hydrogen-burning reactions, another equally exciting period began with critically important ideas from Ed Salpeter and Fred Hoyle that led to the study of the reactions building carbon and oxygen from the helium nuclei that had, in turn, been produced earlier by the fusion of hydrogen. In this way Willy and his team proceeded step by step to study the nuclear reactions that would occur deep within a star at later,

He was a rare individual, a man who will be remembered as much for his wonderful personality as for his many contributions to the world of science.

Below: Fowler and Barnes with Kellogg's new (in 1982) accelerator, known as the "Yellow Submarine." Barnes is explaining how the focal properties of the beam change as it turns a corner.

higher-temperature stages of the life of the star, leading to its final explosive demise as a supernova—if the star were massive enough—or to its protracted quiescent decline into oblivion.

After the helium-burning program was well established, Willy elected to take a sabbatical year, 1954–55, in Cambridge to work with Hoyle. He met Margaret and Geoffrey Burbidge, and the four of them formed a highly fruitful collaboration that continued at Caltech, resulting in the publication in 1957 of their seminal work showing that all of the chemical elements could be produced in the cores of stars. This work, still referred to as B^2FH from the names of the authors, remains largely intact 40 years later. (Many of the same conclusions were reached independently by A.G.W. Cameron, also in 1957.)

{Barnes then recalled other milestones of Fowler's scientific career, including his farsighted work suggesting the detection of neutrinos from the nuclear reactions in the sun's core; his work with Hoyle on producing a more reliable way to gauge the age of our galaxy (and his delight in coining the term "nucleocosmochronology" to describe the field); his joint work with Hoyle and Bob Wagoner on the simultaneous dynamical evolution of and nucleosynthesis in the big bang; and the enduring legacy of his critical reviews of the huge body of experimental reaction data that led to his recommended values for astrophysics calculations.}

Willy loved finding felicitous epigraphs for his papers, from Samuel Pepys to Isaac Newton. A quote from the latter (1704) reads: "The changing of bodies into light, and light into bodies, is very conformable with the course of Nature, which seems delighted with transformations." I can still see, in my mind's eye, Willy's satisfied smile as he finds yet another apt quotation for one of his papers.

As Fred Hoyle said last March about Willy, "The technical description of a man's career says little of what he was like." Willy was above all a great person to meet and to get to know. Working with him was an ongoing exciting experience. His dedication, his irrepressible optimism, and his unquenchable energy made him an inspiration both here at the Institute and in his many other undertakings, the host of academic and scientific organizations he served, science-policy circles in Washington, and committees on national defense policy. Because of his remarkable virtuosity, it is not surprising that Willy was a much sought-after speaker. He was a rare individual, a man who will be remembered as much for his wonderful personality as for his many contributions to the world of science.

Steven Koonin
Vice President and Provost; Professor of Theoretical Physics; BS '72
Caltech

Our memories of people are a collage of the experiences that we have with them, and I had more than 25 years to build up my mental image of Willy—as his student, his colleague, and his collaborator. My mental image of Professor Fowler is quite dissonant with the decorum that's

Left: Provost Steve Koonin hails a couple of well-known Caltech nonadministrators, and (right) Fowler gets a laugh out of the queen of Sweden.

traditional for occasions like this, and so, rather than the usual solemn recitation of fine qualities and noble achievements, I thought I'd tell you a few of my favorite stories by and about Willy that for me at least capture the essence of the man.

Willy did great things, he had fun while he did them, and he enjoyed involving others in the doing.

Willy loved to party, and one of my recollections stems from a party. It dates not from when I first met him but rather from when my wife, Laurie, did. In June of 1972, Borje Persson, a physics professor in West Bridge for whom I had worked, threw me a graduation party. Since I had also spent a good deal of time in Kellogg, many Kellogg folks were there as well, and, as might be expected, much alcohol was consumed. At some point during the evening Willy sneaked off alone to a bedroom. Laurie's introduction to the great man occurred when a co-conspirator summoned her to the bedroom, from which she burst giggling hysterically five minutes later. She never told me what went on in there with Willy, but I want to talk to Bob Christie about that mirror and hat.

That Willy could instantly put anyone at ease is shown by the picture above. The real reason why these people are laughing is perhaps less well known. It seems that in the course of the Nobel preparations, Willy had been shown a picture of the royal family. During the dinner conversation our hero remarked to the queen that, since he had had the chance to admire her children, it was only fair that she have a look at his grandchild, and he promptly pulled out a picture of Spruce. As he did so, he asked whether Her Majesty knew the difference between a grandfather and a grandson. She replied, "Yes, Willy, I think I do." (He'd already taught her to call him Willy.) "But I'm not certain it's what you're thinking of." Willy then answered his own question: "A grandfather always carries a picture of his grandson, but a grandson never carries a picture of his grandfather," prompting the hilarity caught by the photographer.

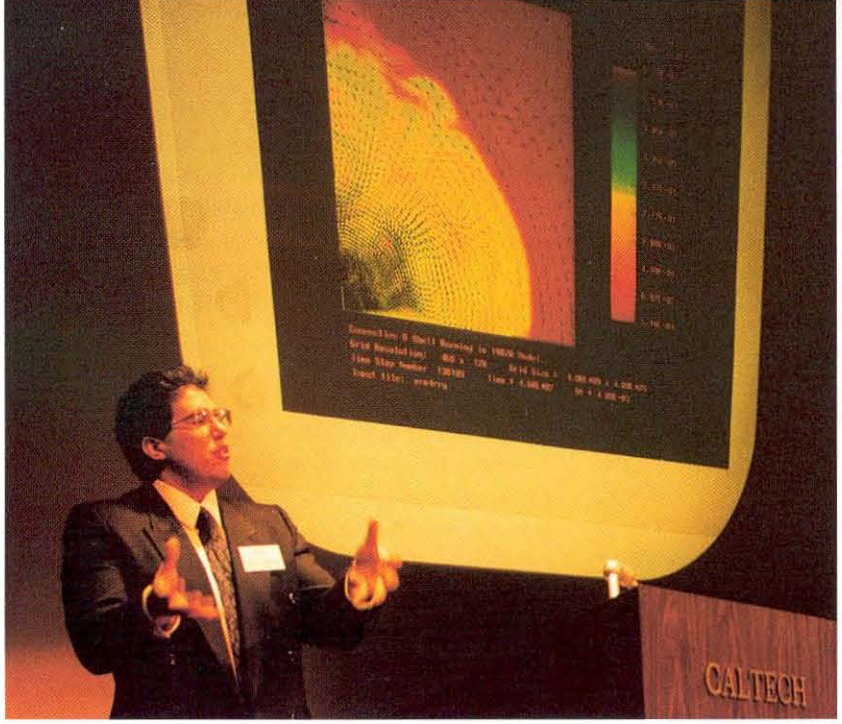
Willy seemed to have a story for every occasion. You've already heard from Spruce the one about experts, and there's another one about lawyers. But one whose recollection helps keep me humble in my present position is the one about administrators. Willy had a standard response to the question of why he never became an administrator. It seems that when Professor Fowler was visiting a small college to deliver a lecture, he stopped in to use the men's room. As he turned to use the electric hand dryer on the wall, he noticed a graffito scrawled next to it: "Push here to hear the dean speak." That was enough to cure him of administration.

I have many more Willy stories, as I'm sure everyone does, but I think the common threads of all of them are that Willy did great things, he had fun while he did them, and he enjoyed involving others in the doing. That combination of qualities is something that we should cherish and aspire to.

Grant Bazan
Research Associate, Steward Observatory
University of Arizona

Like many of you here, I owe a great debt of gratitude to Willy Fowler for what he has done for stellar nucleosynthesis. His direct contributions to the field obviously include his seminal paper, Burbidge, Burbidge, Fowler and Hoyle, and many other papers on nuclear reactions that either laid the foundation for nucleosynthesis or clarified any lingering doubts that we might have had about a certain reaction chain. I was asked today to comment on my impressions of Willy's contributions to the current state of stellar nucleosynthesis and to prognosticate about the future of it. Even though I met him only a few times and don't have a rich history of interaction with him, I do still feel that Willy is a part of me, because I am a product of the people with whom he has populated the field. So the field of nucleosynthesis rests in good hands because a piece of Willy lives on in all of us who continue to do this work.

In the current state of nucleosynthesis, the extent to which we can explain what we see in



Grant Bazan describes the stellar evolution models now possible with current computer power, in particular those that include convection in the latter stages of a star as it becomes a supernova.

I think that within the next 10 years we might actually be able to explain maybe one iota more than what Willy has already taught us.

the universe is the result of the contributions of Willy Fowler. Just from simple assumptions about how a star evolves, from compilations of nuclear reaction rates, we can estimate the chemical abundances in individual stars (very different from the abundances on Earth) and come remarkably close to what is observed, even though just a small error in these rates can make a huge difference. I think Willy would be very proud of how the field looks now, especially when you consider that these complex processes work as well as they do theoretically.

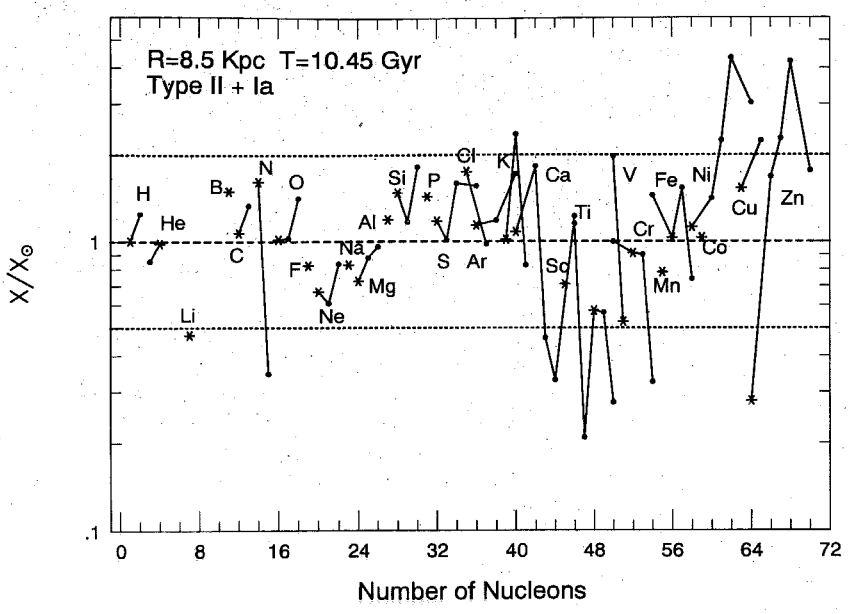
We can actually plug the sum of all the stars —the output, the chemical yields that we calculate—into an even simpler model of chemical evolution and come out with individual isotopic abundances that match those on Earth within a factor of unity. I find this simply amazing. This is probably the greatest testament to Willy's life. This is what he set out to do, and in a way he is doing it still.

What is there, then, left to do in stellar nucleosynthesis? There are still lingering questions concerning individual isotopic reactions, things in meteorites that we can't explain using the simple assumptions of stellar evolution. We are now at the point where computer power allows us to employ real hydrodynamics, real assessments of nuclear reactions, and put these into real stellar evolution models. One example of such a model is our attempt to put convection into the latter stages of a star as it goes into a supernova. The computer power necessary to do this was not available even three to five years ago. With this better technology, combined with the knowledge that has been accrued since Willy Fowler began it, the field of stellar nucleosynthesis rests on very firm ground. I think that within the next 10 years we might actually be able to explain maybe one iota more than what Willy has already taught us.

Frank Timmes
Compton Gamma Ray Observatory Postdoctoral Fellow
Clemson University

Within the notion that there are scientific families that parallel personal families, this photograph always puts a smile on my face. For then this picture shows my great-grandfather, my grandfather, and my father, along with several uncles: Uncle Ray, Uncle Mike, and Uncle Syd. I take some of my fashion tips from Grandpa there, and Pop is looking pretty cool in his black Levis.

I wasn't one of William Fowler's graduate



Recent models of the chemical evolution of stars have calculated the abundances of stable isotopes from hydrogen to zinc, trying to show that, after many rounds of star formation, this process will eventually reproduce the sun's known composition. The y-axis here gives the calculated abundance divided by the measured solar abundance. The most abundant isotope is marked by an asterisk, and isotopes of the same element are connected by solid lines. If this calculated stellar composition were the same as the sun's, the isotopes would all lie on the horizontal dashed line. They do, however, replicate solar composition within a factor of two, represented by the horizontal dashed lines.

students or postdocs, and yet I consider Dr. Fowler to be one of the most important influences upon my scientific life. For without the sustained advice, unwavering support, and friendship of his students and collaborators, much, if not all, of the nuclear astrophysics that I am involved in would simply not exist as it does in its present form. I am highly appreciative, and greatly indebted.

Since my principal connection with Willy is through his science, I would like to spend a few moments on one aspect of that relationship.

Burbidge, Burbidge, Fowler, and Hoyle composed a broad and compelling paradigm of how the elements are synthesized in stars. They identified the various processes that operate in stellar interiors, and predicted the chief nucleosynthetic products from the major nuclear burning stages. Some of the details have changed, especially in the light of new physics that was unknown in the late 1950s. For example, scattering by intermediate vector bosons gives rise to neutral currents, which add a source of neutrino cooling. This cooling affects the core structure of a massive star, which in turn determines, to some extent, the detailed nucleosynthesis. Burbidge et al. and Cameron posed the following very important question: can the nucleosynthesis that takes place in stars and is forcefully ejected, eventually, after many rounds of star formation, reproduce the measured solar composition? I wish to briefly address this question.

By the mid 1980s various groups had run detailed nuclear reaction networks on specific stages of stellar evolution: core silicon burning, shell oxygen burning, and neutron capture reaction sites to name just a few. These specific studies suggested that a sizable portion of the solar composition could be synthesized. Supernova 1987A arrived and offered several observational tests of stellar evolution and nucleosynthesis, along with providing a few unexpected features. In the early 1990s the index n in Moore's Law (computer speed doubles and price halves every 18 months) had become significant enough to allow the routine use of detailed nuclear reaction networks in very finely gridded stellar evolution models. Coupled with an increase in our knowledge of the physical and evolutionary properties of our galaxy, the question posed by Burbidge et al. began receiving fresh attention.

The graph at left shows an example from the results of these recent stellar-chemical evolution studies. In terms of absolute solar abundances, the stable isotopes from hydrogen to zinc range over some 10 orders of magnitude. There are many uncertainties that affect the spread and pattern in the figure, for example: the treatment of convection, residual disagreement on key nuclear reaction rates, functional form of the star formation rate, and even the measured abundances themselves. Certainly this graph does not represent the final answer, nor the first, but it is very encouraging that the isotopic solar composition from hydrogen to zinc is replicated to within a factor of two.

Willy played a central role in this calculation— directly, by his compilations of the necessary nuclear reaction rates, and indirectly by training and motivating his students, grandstudents, and great-grand-students. I think a reasonably correct calculation of the isotopic solar composition is a beautiful example of the adventure associated with connecting nuclear physics to astronomy. It is very exciting, and an honor, to assist in propelling the science which Willy had such a profound influence on into the next millenia. □

{The "family" photograph on the opposite page was taken by David Arnett in front of The Green Man pub in Grantchester, England, at lunchtime, ca. 1971. From left to right: Syd Falk, Kem Hainebach, Mike Howard, Stan Woosley (identified as Pop in the text), Ray Talbot, F. C. Michel (Caltech BS '55, PhD '62), Cliff Morris, Don Clayton (MS '59, PhD '62; identified as Grandpa in the text), and Willy Fowler.}