# A Passion for Science

©Julien Clinton Sprott[1]

December 31, 2015

Dedicated to my parents without whom none of this would have happened.

# Preface

> Memoirs means when you put down the good things you ought to have done and leave out the bad ones you did do. —Will Rogers

When one spends seven decades consuming worldly resources and benefitting from the efforts and kindness of others, it seems fitting to give something back in the form of a written record of one's experiences and the wisdom gained over a lifetime. This book is my effort to do that. It is not an autobiography, nor even a conventional memoir, but rather a collection of short narratives recounting events that influenced the choices that I made in life and short essays describing some of my theories and ideas, arranged somewhat chronologically, but with considerable overlap. It is a work in progress and will be continually updated as time and inspiration permit.[1]

While I do not have biological descendants (to my knowledge) who would be a natural audience for this work, I have had the good fortune to spend a lifetime as a university professor working closely with about a hundred graduate and undergraduate research students, teaching about ten thousand physics undergraduates, and reaching at least a hundred thousand children and adults through live and recorded presentations of *The Wonders of Physics*. Add to that the readers of my books, publications, and website,[2] my relatives, friends, and colleagues, as well as curious strangers and possible future historians, and I have reason to hope that this work will be read by others in addition to the considerable pleasure that its writing has given me.

There is always the danger that I have remembered things incorrectly or said things that are inaccurate or incomplete, and I welcome corrections or criticisms, especially if those things pertain to you. The index at the end includes the name of everyone mentioned here except for a few people who are mentioned only by first names to protect their privacy.

[1] The current version of this document is at http://sprott.physics.wisc.edu/memoirs.pdf.
[2] Sprott's Gateway is at http://sprott.physics.wisc.edu/.

An underlying theme is the passion for science that I have had since my earliest days, and how this was nourished as a child, developed as a student, and exploited as a scientist. I hope to inspire some youngsters to follow in my footsteps, even as I followed those before me and perhaps avoid some of the mistakes I have made. My lasting contribution to society is most likely to be the research I have done, the things I have written, and the lives I have influenced. I hope you will take pleasure and inspiration in reading the words that follow.

*Julien Clinton Sprott*
*Madison, Wisconsin*
*December, 2015*

# Contents

# Chapter 1

# The Memphis Belle

We spend our years as a tale that is told. —Psalm xc.9

My parents must have enjoyed Christmas Eve in 1941. I surmise as much by subtracting 266 days from my birth date of September 16, 1942. I mention this not just because conception is a logical starting point for one's memoirs, but because it seems curious that my father, Frank Sprott, and his wife Ila (also called 'Jimmie') would choose to have a child two weeks after the Japanese bombed Pearl Harbor. I suppose they had to do something while waiting for their other child, a ten-year-old son named Frank Jr., to fall asleep so that they could put the customary Christmas presents under the tree, but it's hard to escape the conclusion that my entrance into the world was something of an accident, although I never felt unwanted.

I suppose it is equally plausible that I am a result of my father's attempt at preserving his legacy in the event that he did not survive the War because he joined the Navy shortly after the US entered World War II. The other sailors called him 'Pop' because he was married with children and at age 32 was somewhat older than most of them. His age probably kept him out of combat, instead working at a Naval base in North Carolina where he spent the first year of my life apart from the rest of the family who lived in Memphis.

For anyone who witnessed the sacrifices and suffering during the War or for one born a few decades later when wars were not so noble, it's hard to understand the feelings that children who were born during or shortly after World War II had about the military and about the scientists who developed the bomb that so abruptly ended the War. A favorite children's game was 'playing war,' and by age six, I was dressing in my brother's high school

ROTC (Reserved Officer's Training Corps) uniform and marching around the yard.

A decade later, I followed the tradition of my father and brother by becoming an officer in high school ROTC, eventually reaching the rank of lieutenant colonel. I might have had a military career had I not developed such a love for science. The four hundred M-1 rifles and firing range in the basement of our high school probably didn't last much beyond my graduation in 1960 when I entered MIT with a student deferment from the draft. My friend Clyde Wentz was a fellow ROTC officer who spent much time at the rifle range and carried his target rifle to school on the city bus most days, which vividly illustrates how different life was in those days and how embedded the military was in the culture.

Bob Burns and me as high school ROTC officers in 1960.

One of my earliest memories was when my brother used to take me to the National Guard Armory in Memphis where a B-17 bomber called the Memphis Belle sat outside on a pedestal. It was open for anyone to explore until it was eventually vandalized and closed to the public. I would crawl into every space inside that airplane and would sit in the cockpit pretending to be the pilot or in one of the gunner's positions pretending to shoot down enemy planes. I suppose I was seven or eight years old at the time. I didn't know much about the airplane or its history except that it was used in the War, and it was filled with instruments, electronics, and other gadgets that certainly fueled my budding interest in science. I hadn't seen the documentary film about the plane and its crew that was made in 1944 or the dramatization that was later made in 1990.


The Memphis Belle.

That early exposure to airplanes, as well as a ride in a Piper Cub that my father arranged with one of his friends, planted the desire to someday learn to fly—a dream that was fulfilled only at age 28 after finishing college and graduate school. Shortly after taking my first real job as a research physicist at the Oak Ridge National Laboratory in Tennessee, I saw a plane flying over the city carrying a banner reading 'Learn to Fly—Powell Airport.' The next day I was at the airport taking flying lessons, and within a few months I became a licensed private pilot.

The story of my connection with the Memphis Belle might have ended there except for a small announcement I saw in the newspaper after some thirty years of flying small airplanes and having many adventures of my own, some of which are described in a later chapter. It said that the B-17 replica that was used in the 1990 movie along with the pilot of the original Memphis Belle were coming to the airport at Madison, Wisconsin where I then lived. It never occurred to me that the pilot would still be alive, and I knew I had to meet him.

On the appointed day, May 31, 2003, I went out to the airport and saw the plane that looked so familiar, and thoughts of the past poured over me. The plane somehow seemed a bit smaller than I remembered, but everything looks larger than life when one is a child. I suppose I should have paid the $10 they were asking for a walk-through of the plane, but somehow I felt that I should not have to pay to renew an acquaintance with such an old friend, especially since it was not even the real Memphis Belle. Anyway, I was mainly there to meet the pilot.

Col. Robert K. Morgan (1918–2004), pilot of the Memphis Belle, at age 85.

And so I hurried over to the hanger where I saw an elderly gentleman sitting alone at a small table with an array of photographs spread before him. He seemed like a small man, but with a wiry, rugged appearance, and I could imagine him being able to pilot a B-17 even at his advanced age. I tentatively asked 'are you the pilot of the original Memphis Belle?' 'Yep, I'm Robert Morgan.' We shook hands, and I told him how I had grown up in Memphis shortly after the War, developed a love for aviation by crawling through his airplane as a child, and eventually became a private pilot. 'You're not the one who vandalized it, are you?' he asked with a smile. 'Absolutely not! In fact, I was heartbroken to see what others did to the plane and sad when I was no longer able to go inside of it.'

I paid $10 to a woman who was hovering nearby to purchase a photograph of the plane with its original crew, and I asked Colonel Morgan to autograph it for me. 'To Clint ... Best wishes ... Robert Morgan—Pilot' he wrote and added an arrow pointing to himself in the photograph. I regret that I didn't think to take my camera so that I could have had a picture of the two of us together.


**Memphis Belle Crew: Bassingbourn, England, May 17 1943**
**First to complete 25 Combat Missions**

**( L to R) Harold Loch, Top Turret Gunner; Cecil Scott, Ball Turret Gunner; Robert Hanson, Radio Operator; Jim Verinis, Copilot; Robert Morgan, Pilot; Chuck Leighton, Navigator; John Quinlan, Tail Gunner; Tony Nastal, R Waist Gunner; Vince Evans, Bombardier; Bill winchell, L Waist Gunner.**

The crew of the Memphis Belle in a 1943 photo autographed for me by the pilot, Robert Morgan.

The story ends on a sad note. A year later I saw a small announcement in the newspaper that the pilot of the original Memphis Belle had died on May 15, 2004 of complications from a fall. I will always be grateful that I had the chance to meet the pilot of the plane that kindled my interest in aviation and eventually led to a career in science.

# Chapter 2

# Adventures of Two Young Hams

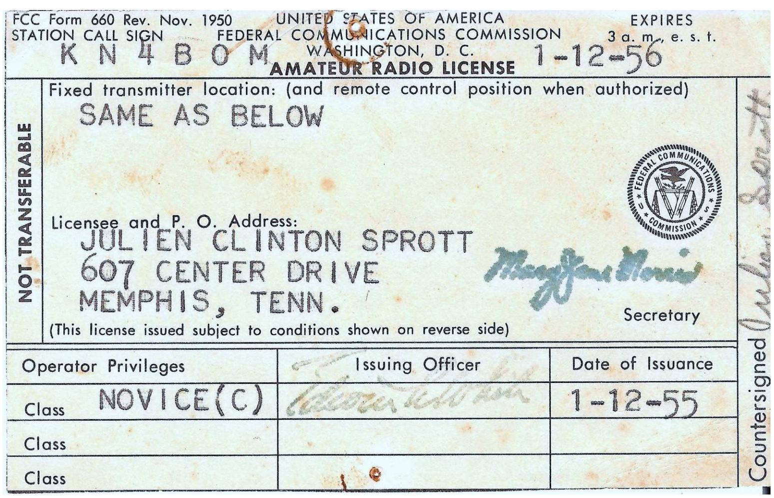
> I am often asked how radio works. Well, you see, wire telegraphy is like a very long cat. You yank his tail in New York and he meows in Los Angeles... Radio is exactly the same, except that there is no cat. —Attributed to Albert Einstein

In the 1950s, technically-inclined teenagers (perhaps now called 'nerds') gravitated toward an interest in amateur radio, which was a rather different hobby than it is today. Amateur radio operators ('hams') had to pass a government examination in radio theory and regulations and a Morse code test to become licensed and receive personal radio call letters. They built much of their own equipment and used it to communicate with ('work') other hams throughout the world (DX) using either voice (AM) or code (CW). The introduction of the Novice license in 1951 with its simpler written examination and five-word-per-minute (WPM) code test allowed even preteens to become licensed.

There are many facets of amateur radio in addition to talking to friends and strangers around the World (ragchewing). Some hams like to build equipment (homebrewing), design and operate terrestrial and satellite repeaters, bounce signals off the moon (EME), explore microwave communications, operate at low power (QRP) or in exotic locations (DXpeditions), participate in transmitter hunts, enter contests in which the goal is to communicate with as many other hams as possible, and try to contact as many countries as possible (chasing DX).

My interest in amateur radio began at a early age when I used to listen to hams talking to one another (QSO) on the 40-meter band with an inexpensive short-wave radio that my parents had bought. My father had a friend, Buford Nichols, who was a ham (call letters W4FG). For some reason, perhaps because it was easier to understand through the interference of the airwaves, he used his middle name of ‘Harry’ as his radio name (his ‘handle’), and it was largely in emulation of him that I began using ‘Clint’ (short for my middle name of ‘Clinton’) as a handle. He had a shack in his back yard in Memphis, packed with homemade radio equipment that he used to communicate around the world. I was enthralled by visits to his shack, and determined to become a ham.

Shortly after my twelfth birthday, my parents accompanied me to a weekly class for prospective hams sponsored by the local amateur radio club in Memphis. The Morse code part of the class was taught by a precocious teenager, Frank Dietrich, (W4CLL) who was interested in physics and went on to a successful career in nuclear physics. At the conclusion of the class, we all received our Novice licenses, although my parents never went further with the hobby. Instead, Frank served as a mentor, getting me started in ham radio and inspiring me to follow his footsteps into physics.


FCC Form 660 Rev. Nov. 1950
STATION CALL SIGN
K N 4 B O M
UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D. C.
AMATEUR RADIO LICENSE
EXPIRES
3 a. m., e. s. t.
1-12-56
NOT TRANSFERABLE
Fixed transmitter location: (and remote control position when authorized)
SAME AS BELOW
Licensee and P. O. Address:
JULIEN CLINTON SPROTT
607 CENTER DRIVE
MEMPHIS, TENN.
Secretary
(This license issued subject to conditions shown on reverse side)
Countersigned

| Operator Privileges | Issuing Officer | Date of Issuance |
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My first amateur radio license issued in 1955, showing the rust from the thumbtack that attached it to a bulletin board during my teenage years.

It is hard to overstate the influence that ham radio had on my life and career. In addition to the obvious education in electronics that it provided, it enabled me to develop mechanical skills in the equipment that I built and modified, social skills in interacting as an equal with hams of all ages, educational levels, and occupations, cultural skills and a geography lesson in contacting hams throughout the world, the mental challenge of mastering the Morse code, and my first exposure to space physics and plasma physics in trying to understand the characteristics of the ionosphere that allowed long-distance radio communication. Before leaving for college, I had earned an amateur extra license, the highest amateur class issued, as well as a first class commercial radiotelephone license with a radar endorsement, which would have allowed me to be the chief engineer at any radio or TV station in the country, and a second class commercial radiotelegraph license, only because the first class license would have required a year's experience as a telegraph operator aboard a ship.

When I got to MIT in 1960, I discovered that many of the students there had radio licenses, and some had acquired multiple amateur and commercial licenses as I had done for no particular reason, but it did provide good bragging rights, especially for someone like me whose preparation for college was inferior to most of the other MIT freshmen. The amateur extra license, however, was a bit of a rarity because it did not confer any additional privileges in those years, and so there was no incentive to get it. It turned out to have been a useful acquisition, since a decade later when I moved permanently to Wisconsin, I was able to acquire the prestigious call letters W9AV as a result of having had one of the early amateur extra licenses. Shortly thereafter, the window closed on the reissue of call letters starting with W9 followed by two letters, and to have one such as AV is unusual since amateur radio call letters were issued in alphabetical order starting with W9AA a century ago in this part of the country. It was difficult to part with the K4BOM call letters with which I had come to be so closely identified, but in those days, the number in the call had to correspond to the geographical location, a requirement that was later rescinded.

Within a year of getting my Novice license, I met Quent Cassen, (W4YMG) only a year older, but already an accomplished ham. We became best friends and encouraged one another's technical interests throughout our teenage years. In 2006, we were asked to write a description of what it was like to be a Novice ham in the 1950s for posting on a website. What follows is a slightly edited version of that co-authored story, which was eventually published in the July 2008 issue of *World Radio*:

* * *

The year was 1955. Dwight Eisenhower was president, and it was a much simpler time, especially in Memphis, Tennessee where 12-year-old Clint Sprott, ex-KN4BOM, has just received his Novice Amateur Radio license in the mail. Two years earlier, 11-year-old Quent Cassen, ex-WN4YMG, had also become a Novice. Within the year we had upgraded to Generals and became lifelong friends, sometimes called the 'CQ twins'[1] by local hams during our teenage years.

Our early Amateur Radio days were spent on 40 meters with low-power homebrew CW transmitters. Hams built a lot of their own equipment in those days, especially teenagers on weekly allowances. Clint mowed lawns, and Quent had a paper route to make enough money to buy the parts to assemble their early equipment. Quent had a Hallicrafters S-40B receiver, purchased from Sears, and Clint used a National NC-98 receiver that Santa Claus had left under the tree. Clint remembers the trepidation with which he made his first QSO on 17 January 1955 with Harvey Krasner, K4ASL, nearly a mile away, on the 40-meter CW Novice band. Quent remembers yelling to his mom 'What should I tell him?' when it was his turn to transmit.

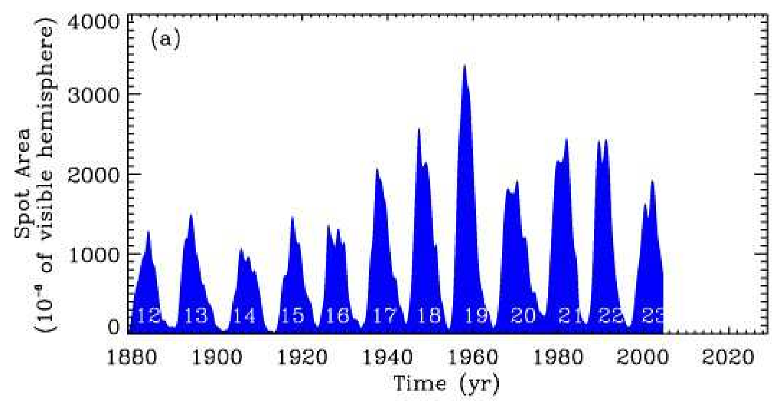
Amateur Radio in the 1950s was quite different from today. There was the thrill of listening to the first satellite to orbit the Earth, Sputnik 1, launched by Russia in October 1957. Sputnik was easy to tune in since it transmitted at 20.007 MHz, just above WWV.[2] Receivers weren't so good in those days, and it helped to have WWV as a marker to find the right frequency.[3] Probably the Russians did that on purpose lest we fail to notice. Propagation was so good in 1957 that we could hear Sputnik much of the way around the Earth during some passes. Sometimes we could go outdoors and see the satellite pass overhead just after dark. There was a 1 kHz Doppler shift on the Sputnik signal as it passed, but the receivers that teenagers could afford weren't stable enough to notice it.

[1]'CQ' is the phrase spoken or sent in Morse code by hams seeking to contact others on the air, arguably a shorthand version of 'seek you,' and coincidentally the initials of Clint and Quent.

[2]WWV is a powerful radio station transmitting time and frequency information by what at the time was the National Bureau of Standards in Washington DC. The agency is now called the National Institute of Standards and Technology, and the transmitter is located in Fort Collins, CO.

[3]Check http://www.amsat.org/amsat/features/sounds/sputnk1b.wav to hear what Sputnik 1 sounded like.

We were surprised how easy it was to work DX with modest equipment. Ten-meter CW was really hot. On the weekends we would get up early and work one European station after another, staying with it all day until stations from Australia and Japan would start to come in just before 10 meters went dead in the evening. The world seemed a very big place to two kids who hadn't ventured far from home. What we didn't know was that sunspot cycle 19, which peaked in 1957, still stands as the all-time record.[4] DX contests were a thrill for us. By 1959, we both had our DXCC certificates[5] and many other operating awards.




The eleven-year sunspot cycle showing the record peak in 1957.

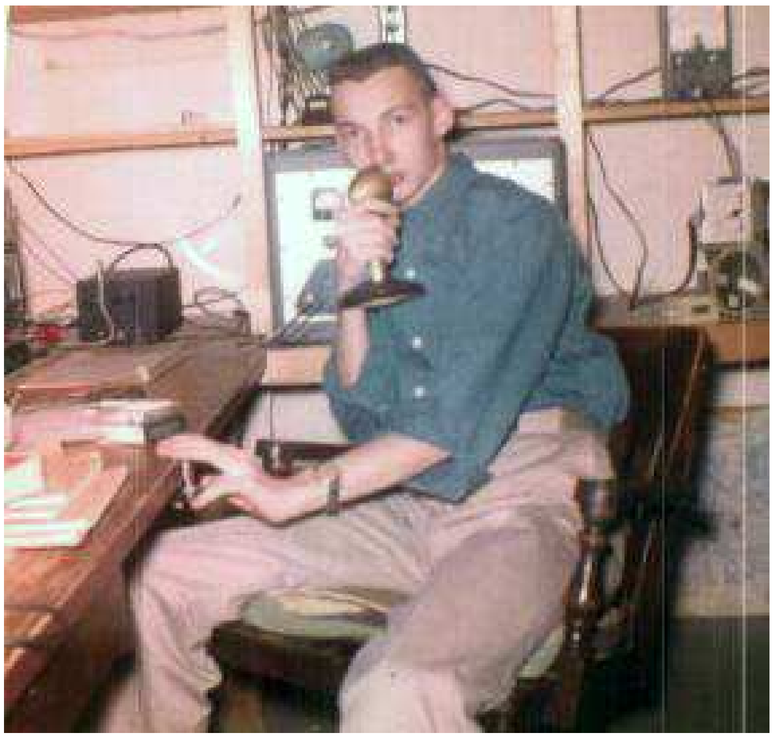
Before we were old enough to drive, we converted a Heathkit 11-meter Citizens' Band transceiver to 10 meters and mounted it on Quent's bicycle. The equipment was all vacuum tubes, and so we had to convert the output of a small wet cell battery to high voltage DC to power the tubes. The bicycle had an 8-foot whip antenna on the back, constructed from an old fishing pole. It was fun working locals as well as DX on 10 meters AM with only 5 watts while pedaling down the street. Everyone thought we were crazy. Why would anyone want their own personal communicator to take with them in their vehicle?

While still in high school we each built our own Heathkit DX-100 transmitter. The photo is of Clint in his basement shack, in front of his DX-100. We built many other pieces of Heath equipment—receivers, transmitters, and

[4]Sunspots are a measure of solar activity and have a direct and strong influence on the long-range propagation of radio waves that are reflected off the Earth's ionosphere.

[5]The coveted DX Century Club award is given to hams who can prove making radio contact with other hams in at least 100 different countries.

test equipment. Allied Radio in Chicago (via mail order) and the local Amateur Radio emporiums in Memphis (Bluff City and W&W) soaked up a lot of our allowances. We occasionally used the popular World War II ARC-5 Command Set equipment that was readily available and easily adapted for use on the Amateur Radio bands.



Me in my basement 'shack' with the DX-100 transmitter I constructed in the background.

We acquired many inexpensive components from Lazarov Surplus Sales in Memphis, which sold parts by the pound. Clint remembers clipping resistors out of some of the equipment so we didn't have to pay for the weight of the unneeded chassis. Can you blame the workers for being annoyed with us? Much of the war surplus electronics was designed for 24-volt military equipment, but we occasionally found 12-volt amplifier vacuum tubes (1625s) and dynamotors which were the standard way to produce the hundreds of volts needed to power the AM vacuum tube transmitters that some hams put in their cars. We each built 10-meter AM mobile transmitters for our parents' cars, at a time when we were too young to drive. Clint still has


World War II ARC-5 Command Set converted to operate on 40 meters.

an operating version of one of those fifty years later! The other transmitter, unfortunately, went up in flames years later while his mother was driving the car after Clint went off to college.

CW came easy to us, probably because we started so young. We both used mechanical bugs for sending code, and Clint built an electronic keyer using vacuum tubes, but it never quite worked right, sometimes running away and sending things never intended. We got code proficiency certificates for 35 WPM, which was the highest speed for which the ARRL[6] tested. We

[6]The American Radio Relay League is a National organization devoted entirely to amateur radio.


Ten-meter AM transmitter built by Quent Cassen and me for use in his parents' car.

were asked to teach the code to adults who were studying for their General license at the local Amateur Radio school. We would record code practice sessions at 30 WPM on an old reel-to-reel tape recorder and play it back at half speed for our students to practice so that it didn't take so long to prepare the lesson. To keep secrets from our parents, we occasionally 'spoke' to one another in Morse code. Not exactly the same as the Navajo code talkers you've seen in the movies, but you get the idea.

Field Day was always a summer highlight. We often operated W4EM, the club station of the Mid-South Amateur Radio Association (MARA) in Memphis. Quent is tuning the Collins 75A-3 in the picture, and Clint's hand is on the Johnson Viking II transmitter. While still in high school, one Field Day we set up our own station deep in the woods in Overton Park and stayed up all night operating.

Biweekly transmitter hunts were popular in the late 50s in Memphis. The photo shows Quent (at right car door) and Clint (at left car door) of Clint's mother's car before the start of a rabbit hunt. Can you imagine what Clint's mother said after she found out that he had drilled a hole in the top of her brand new 1956 Buick Special! Reluctantly she agreed that it was better to


Mobile club station for the Mid-South Amateur Radio Association.

plug the hole with a 2-meter antenna[7] than just to leave it. Another photo shows Quent's dad, Frank Cassen, W4WBK, recording Clint's mileage before the start of a hunt.

Although transmitter hunts were conducted on 10 meters, the 2-meter antenna was used for VHF communication using retired vacuum tube taxicab radios that we converted to 2 meters. The receiver and transmitter took up most of the trunk space. That was before the days of 2-meter repeaters and commercial solid-state Amateur Radio transceivers.

We used 29.627 MHz for the 'Memphis 10 Meter Mobile Emergency Net.' Everyone was crystal controlled since 7406.6 kHz quartz crystals were easy to get from surplus outlets and VFOs weren't so stable on 10 meters or even common on inexpensive and homebrew equipment. The net met faithfully on Monday and Friday nights, although it seemed no one ever had any traffic.[8] Nevertheless, the operators and equipment were well prepared for the many drills that they took part in.

Once while at Clint's parents' lake home on Pickwick Lake in northeast

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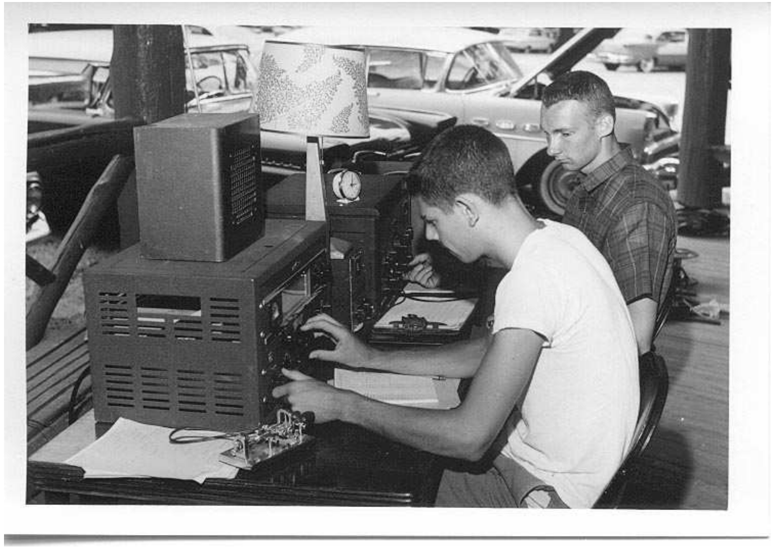
[7] A '2-meter antenna' is actually half a meter (about 19 inches) long since such antennas work best if their length is a quarter wavelength.

[8] 'Traffic' refers to messages passed among hams until they reach their intended recipient, often a member of the public during an emergency when other means of communication have failed.



Quent Cassen and me operating W4EM during Field Day with my mother's car with its hood open in the background.

Mississippi, we decided to go on a DXpedition of sorts. We overloaded Clint's dad's small boat with a gasoline-powered AC generator, a large vacuum tube receiver (SX-100), an Eldico CW transmitter, and a dipole antenna, and set up shop on a tiny island in the Tennessee River, near the dividing line between Alabama and Mississippi—all for the chance to sign K4BOM/4/5 on the air and pretend we were DX. The pileups were feeble (nonexistent, really), but it was our first time to be on the 'wanted' end of a DXpedition after working so many others. Miraculously, we got back to shore without losing any equipment despite the rough seas.

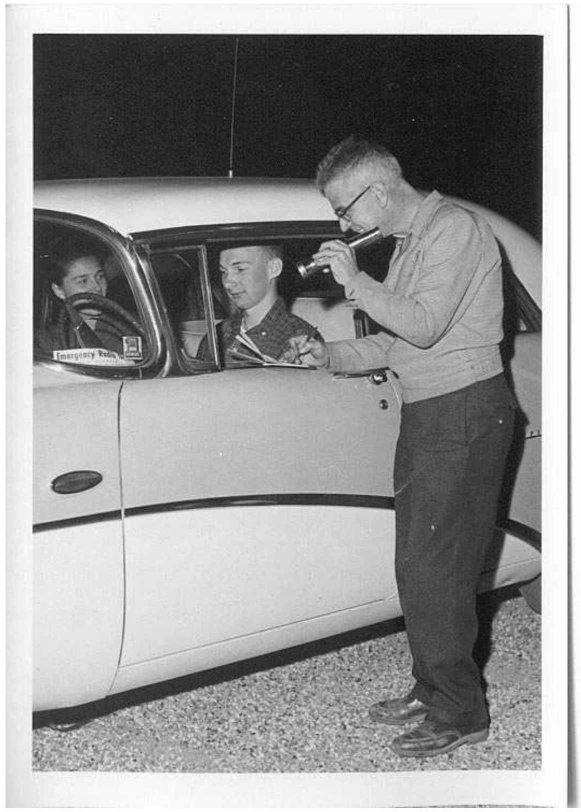
One might think that we always walked the straight and narrow, but unfortunately 'boys will be boys.' Quent had a receiver that could tune to the local police and fire department, and Clint bought at a police auction for $5 a vacuum tube receiver that was on a police motorcycle that had been submerged for a month in the Mississippi River and nursed it back to health. We would often converge on the scene of local calls, first on bicycle and later by car after getting our drivers licenses at age 16. Some of the police began to know us. We would occasionally visit the police dispatcher and help him dispatch cars. We once inquired about getting summer jobs as police dispatchers but were told that one had to be 21 years old to work for the police department, and so Quent took a summer job with the electric


Quent Cassen and me at the doors of my mother's car before the start of a transmitter hunt. With hands on the hood is Harvey Krasner with whom I had made my first QSO several years earlier.

company and Clint delivered packages for his dad's office supply company.

After high school we both went on to college. Clint became a physics professor and Quent an electronics engineer. We have been involved in a lot of interesting technical work in our careers. Without doubt, our start in Amateur Radio with the Novice license opened many doors and launched us into our interesting and rewarding careers.

*Quent Cassen, W6RI*
*Clint Sprott, W9AV*
*December, 2006*



Frank Cassen recording my mileage before the start of a transmitter hunt. Visible on the roof of the car is the 2-meter antenna that I mounted there to the chagrin of my mother.

# Chapter 3

# The Awkward Athlete

Baseball is 90% mental, the other half is physical. —Yogi Berra

Although amateur radio was my main interest as a teenager and occupied most of my spare time, I also dabbled in a number of sports, unfortunately with limited success. Those experiences were valuable in my physical and social development and a useful relief from what would have otherwise been a nerdy existence.

## Baseball

As a young child, I would often participate in self-organized softball games before school and during recess, but I was one of those chosen last to be on the team and relegated to the outfield, although I sometimes played second base. It was clear that I would never be a star, but those games engendered valuable skills.

As a young teenager, my mother decided that I should play baseball for our church-sponsored team. Although reluctant, I liked the uniform, which I would dirty up to appear that I had been playing. I mostly sat on the bench but was allowed to play for an inning or two usually in right field, especially late in the game if the score was lopsided. I rarely got a base hit, but when I did, I made the most of it since I was a reasonably fast runner. I recall once hitting about ten foul balls in a row before eventually being called out on a strike. My season ended when I was hit in the face with a ball and had to wear an eye patch for a week. The optometrist can still detect the damage to my left eye, which is the weaker of the two.

I didn't play ball during high school, college, or graduate school, but when I took a job at Oak Ridge in 1971, I was invited to join the 'Thermos,' a softball team consisting of members of the Thermonuclear Division where I worked. All that education hadn't improved my athletic skills, but I was younger than almost everyone else on the team and could run around the bases faster than most when they let me play. One of the older players pointed out that I was holding my arm wrong when I threw the ball, and my effort to do it his way resulted in such poor accuracy that I was a danger to others standing nearby when I threw the ball. When the season ended, they kindly invited me to play on the volleyball team, but I quickly discovered that I had even less talent for that.

## Swimming

My father thought a good way to teach a child to swim was to throw him in the water and see what happens. I sank to the bottom, and he stepped on me in his rescue attempt. It's true that when drowning, your whole life passes before you, perhaps especially when that life is only of a few years' duration. I was scared of the water for the next several years.

My mother's idea was to enroll me in a swimming class at the local YMCA. For some reason, we all swam in the nude, which was embarrassing even at my young age. I was the last one it the class to pass the test and was happy to be done with that.

Shortly afterwards, our family bought a cottage on Pickwick Lake in northeastern Mississippi where we spent many weekends. I swam frequently at the beach until a poisonous water moccasin appeared in the water with me. I was given the job of killing him with a 22 rifle. It was easier than the time my dad chopped off a chicken's head. They do run around furiously, but briefly, with their head cut off.

Those swimming adventures ended when I left for college, except that one of the first things a new freshman did at MIT was to take a swimming test, and if you can't swim four laps (100 yards), you had to enroll in a swimming class, a requirement that persists even today. I passed with a sigh of relief and have limited my subsequent swimming to an occasional few laps in the motel pool. I suppose it's comforting to know that everyone who graduates from MIT is a competent swimmer.

## Boating

I was more at ease with the floor of a boat between me and the water. My dad liked to fish, and every year he built a small wooden boat that he would use and then give to someone once the next boat was done. Those boats had small outboard motors, and I became skilled at using them at our cottage on the lake and sometimes on the Mississippi River. My dad once flipped a motorboat upside down with me aboard when he hit a wave at a bad angle while going at high speed. Fortunately, we always wore life preservers, and so no great harm was done except that it gave us a scare and destroyed the motor.

I helped my father and brother build a small sailboat that we sailed at the lake. I also sailed the Tech Dinghys on the Charles River at MIT and later discovered that the University of Wisconsin had a fleet of those same boats on Lake Mendota, but I never sailed one there. Years later, I did some serious sailing in the Bahamas, to which a later chapter is devoted.

My first time in a canoe was a week-long camping trip in the Boundary Waters of Northern Minnesota in about 1966. I had paddled boats before, but never a canoe. We departed the dock and made about three full circles before I invented what I later learned was called the 'J stroke.' We managed to swamp the canoe on that trip, getting all our gear completely soaked. I had many subsequent, mostly successful canoe trips on the Wisconsin, Kickapoo, and Sugar Rivers, as well as local Madison lakes.

Those adventures were all in quiet water, but I also did some whitewater rafting on the Wolf and Peshtigo Rivers in northern Wisconsin. For years, I have owned a succession of small rubber rafts that I use frequently for day trips, mostly on the Sugar River, where one floats for a few hours down the river, deflates the raft, puts it is a backpack, and hikes an hour back to the car along the road. It's a sport that I claim to have invented—or at least perfected.

## Hunting and Fishing

Both my father and brother were avid hunters and fishermen, and my mother fished as well. They encouraged my participation, and I gave it a try. I can't recall ever killing anything except for an occasional fish off the pier at our cottage. Duck hunting requires one to get up at four o'clock in the morning

Canoe trip on the Kickapoo River in 1999.

and sit quietly for a few hours in a cold blind in the middle of a lake as the sun rises. The shotgun gives quite a kick that was rather uncomfortable for my lanky, somewhat frail frame. The whole activity seemed rather boring, and not very rewarding. I had better things to do.

I did develop a knack for frog gigging, not so much because I enjoyed killing frogs or eating them, but because I took a certain perverse pleasure in subjecting unsuspecting friends to this gross pastime. One takes a boat out on the lake in the dark and quietly paddles along the shoreline while directing a carbide lamp at the shore, looking for a pair of shining eyes. When contact is made, you hold the light on their eyes until getting close enough to stab the frog using a six-foot pole with sharp barbed points on the end. You then bring him into boat, knock him unconscious with the paddle, cut off his legs, put them in a bucket, and discard the frog body into the lake. Then you take the bucket of legs home to mom who, like any good southerner, knew how to cook them. They taste like a cross between chicken and fish. In retrospect, the whole activity seems rather cruel and barbaric, and I doubt that I could do it now, but I was never much of a vegetarian, and so I must admit that much of the food I eat required that someone kill an animal. Southern boys raised in the 1950s were supposed to be hunters and to view wildlife as a food source, not something to be protected and preserved.

## Tennis

If there was any sport for which I developed some competence, it was tennis. During the summers of 1959 and 1960, I spent four or five hours many days playing with Clyde Wentz, a friend from high school, and a fellow ROTC officer. Clyde beat me regularly, but I was good enough that he continued playing with me.

When I got to MIT in the fall of 1960 and avoided the swimming class, I took the easy way out and enrolled in an intermediate tennis class since all students were required to take physical education during their freshman year. I was one of the best in the class, and the teacher, who was also the coach for the varsity tennis team, liked to play with me since I could give him a challenge. He encouraged me to join the team, but I knew I had already reached the limits of my abilities, and by that time my attention was turning to more academic pursuits. When winter came, I enrolled in the squash class, since that was another racket sport, but my tennis skills didn't seem to transfer, and I eventually sold my squash racket to Harold Forsen, a nuclear engineering professor at the University of Wisconsin.

It was another decade before I began playing again as a new faculty member at Wisconsin. I had a succession of tennis partners and played sporadically until George Rowlands made a series of visits to Wisconsin in the late 1980s and early 1990s. He was a physicist at the University of Warwick in England and belonged to a tennis club in the shadow of Warwick Castle. Despite being ten years my senior, he beat me regularly, but he was always willing to play, good sport that he is.

## Skiing and Skating

When I moved back to Madison in 1972 to join the faculty, I decided that a resident of Wisconsin should do some winter sports. Melanie San Fillippo, with whom I had also played tennis, got me interested in downhill skiing, and we skied most of the hills in Wisconsin and a few others. I continued skiing occasionally for the next decade, eventually serving as a chaperone for the Hoofers, the University's outing club, for a ten-day trip to Taos, New

Mexico. They were quick to tell me that I was not there to enforce morals but was merely a representative of the University. Fortunately, they were well behaved, and the only incidents were three broken legs and a few parties with marijuana, which was common in the 1970s among college students. The experience of skiing in the Rockies did dampen my desire to ski in Wisconsin, and I think I only downhill skied one other time about ten years later. When I purchased my lift tickets, they made fun of my old-fashioned skiis, and I figured I had had enough of that. I then took up cross country skiing, which I did sporadically for the next two decades, but with limited ability.

Cross country ski trip in northern Wisconsin in 1999.

I had also learned to ice skate while at MIT, but I did that only occasionally over the years. I was always a bit wobbly, and my ankles would begin to hurt after ten or fifteen minutes. I finally bought some new skates, a pair that had been worn briefly by a Badgers hockey player and returned. That helped a bit, but it was more pain than pleasure, and it took a long time to put on and take off the skates. We had a couple of ice skating contra dances, which were amusing since many of the dancers skated almost as poorly as I did, and so there was a lot of hanging onto one another to keep from falling while trying to negotiate the patterns.

# Bicycling

The bicycle was my main mode of transportation until I got a driver's license on my sixteenth birthday. From second through eighth grade, I often rode my bike to school, about a mile away, and to Quent's house, about the same distance. I didn't own or much use a bike again until 1973 when I settled into a faculty job at Madison. I would commute the three miles to campus during half the year until the weather got cold. Eventually I came to rely on it for most travel in Madison since the town is small and bike-friendly, and parking around the campus and downtown is often a problem.

Bicycle riding in 2011.

I mostly considered the bike as a commuter vehicle, but I also did some recreational day trips. Wisconsin was one of the first states to convert abandoned railroads to bike trails, and I biked many times on the Elroy-Sparta (32 mile), Sugar River (23 mile), Military Ridge (41 mile), and Capital City (34 mile) trails, as well as around Lakes Wingra, Monona, and Mendota.

In all those years, I only had two accidents, one when I was very young, and I still carry a small scar on the back of my right hand from falling on a gravel-covered road. Half a century later, I had a similar accident when I tried to bump up and over a curb without getting off the bike. I was going a bit too slow for the height of the curb and went over the top of the handlebars, landing face down on the concrete. My bike helmet was of limited use in protecting my forehead. Fortunately, it was within sight of the University Hospital emergency room. The doctor who stitched my forehead turned out to be a former student. I still have a small scar above my right eyebrow.

The next day, in explanation of the bandage on my forehead, I told my physics students, many of whom were premeds, that there are three morals to this story: 1) Always wear a helmet when biking. 2) Don't do stupid things. 3) Always be good to your students since one may someday end up treating you in the hospital. The last thing I would want to see in the emergency room is a disgruntled former student. 'I remember you; bend over.'

As a bike commuter, I do have one suggestion for our lawmakers regarding stop signs, which virtually no bicyclist obeys. It is physically demanding to come to a full stop and then restart on a bicycle, usually requiring a difficult sequence of gear shifts, and one would have to dismount the bike to be in complete compliance since a stationary bike is unstable. Such actions arguably are less safe than simply proceeding through the intersection slowly and carefully. Furthermore, any law that is disobeyed by nearly everyone is probably a bad law, and this one, like helmet laws and seatbelt laws, is intended to protect us from ourselves since a bicyclist is not likely to injure a motorist. Pedestrians should continue to have the right-of-way over both cars and bicycles as they do now. The city of Madison and the Village of Shorewood Hills where I live have bike police, teenagers who pedal around on their own bikes and issue warnings and tickets for failing to stop and other offenses.

My suggestion is simply that stop signs be interpreted as yield signs for bicycles, which would seem to satisfy the intent of the law. At the least, someone should determine whether the stop signs are having their intended effect. One could argue that considerable time and fuel could be saved by adopting the same rule for cars, but I'll leave that battle for someone else. As a semantic aside, 'yield' is a better description of what we want vehicles to do than 'stop' since the latter does not imply that we must remain stopped until other vehicles are clear or that we may thereafter proceed.

# Running

I never had much use for running since it is a lot more work and a lot slower than biking. Then I met Debbie Aks who used to run regularly. I thought it was silly. Somehow she convinced me to join her for the annual Crazylegs Classic, a five-mile run/walk benefit for the Athletic Department held every April. It draws upwards of 20,000 participants each year. She assured me that she would run at my speed and not leave me behind. To the surprise of us both, I outran her! I was in good condition from regular biking and dancing, and she wasn't feeling well that day. I was pretty sore for the next few days. That experience didn't convince me to take up running, but I have done the Crazylegs Classic almost every year for the past decade. It's the only time I run during the year, and I do it partly to calibrate my physical condition. No doubt, I could greatly improve my performance with a bit of training, or at least so I would like to think, but I view that as cheating, and it would compromise the experiment.

In 2004, they started giving runners a timing chip that recorded their time to a precision of one second. My five-mile times for the past few years are 2004: 50:45, 2005: 50:47, 2007: 54:40, 2008: 54:14, 2009: 54:08, 2010: 48:53, 2011: 50:06 (two broken ribs two months earlier), 2012: 53:47, 2013: 57:38, 2014: 54:58, 2015: 55:47. It would appear that age is starting to show its effect. I do move up in the rankings as I qualify for older age categories. My doctor says I'm aging well and that I should continue doing whatever I'm doing, which I took as permission to continue eating my usual diet of junk food.

Some years ago, I became interested in the power requirements for running and walking at various speeds and developed a mathematical model that predicted a plausible value for the speed above which running is more efficient than walking as well as the maximum speed at which one can safely walk on a slippery surface, but that work was not fully developed and was never published. Without a doubt, one can study sports scientifically, and the 2010 season of *The Wonders of Physics*, a lecture/demonstration program described more fully in a later chapter, had as its theme 'The Physics of Sports.'


Crazylegs Classics run in 2008.

# Chapter 4

# Forays into Physics

> Physics is becoming so unbelievably complex that it is taking longer and longer to train a physicist. It is taking so long, in fact, to train a physicist to the place where he understands the nature of physical problems that he is already too old to solve them. —Eugene Wigner

> All science is either physics or stamp collecting. —Ernest Rutherford

People sometimes ask how I got interested in physics. It's a difficult question to answer because I cannot remember a time when I was not interested in it, although I was probably a teenager before I knew that the term 'physics' encompassed those things that most excited me. My father's answer was to recount the time before I could walk, when I carefully spread the prongs of a bobby pin apart and inserted it into a wall socket. He claims that I spent a lifetime trying to understand where the sparks came from.

Perhaps he was right because my earliest memories were of collecting scraps of wire and connecting them randomly to various discarded electrical devices. I was wise enough—or perhaps I was cautioned by someone—not to try to plug in those creations. As I got older, I would delight in disassembling old radios and televisions and saving the parts in carefully labeled cigar boxes to use in later projects. That early interest in electricity led eventually to my main teenage hobby of amateur radio, as described previously.

However, electricity was not my only scientific interest. My parents bought me a chemistry set, and I did most of the suggested experiments, although it seemed rather smelly and messy by comparison. I must have been very young, because I was puzzled that many of the common chemical elements I read about in the encyclopedia were not included in the set. At my request, my dad would bring home bottles of colored liquids that he said were hydrogen, oxygen, and nitrogen. I would mix them together, but not much happened. I even tried tasting a mixture of hydrogen and oxygen, and it did taste like water as I expected. Only years later did I conclude that the liquids were probably water with a bit of colored ink.

The house in Memphis where I lived with my parents from second grade until leaving for college.

I was fascinated by things that burned and exploded. I set off firecrackers and cherry bombs and occasionally launched toy rockets. Somehow I discovered that one can fill a quart-sized metal can with gasoline and set it on fire with only a slow burn of the surface. It was a lot more exciting to kick the can gently while it was burning, which caused a brief billowing flame. One time I kicked it a bit too hard, and it tipped over and spilled right next to the wall of the garage. Fortunately, I had a garden hose nearby and managed to extinguish the flame before it burned down the garage. I'm not sure my parents ever knew about that, but they must have wondered how the wall got that black color.

I also got interested in photography for about a year. I had a simple box camera and a darkroom equipped with all the necessary chemicals and an enlarger. The black and white prints I made never looked nearly as good as those developed at the drug store, probably because my equipment was not very good, and so that interest soon waned.

My dad also helped me build a rather elaborate model electric train set in the basement with realistic scenery—mountains, tunnels, and a river running through it. I think he enjoyed making it more than I did, and I was mostly interested in the way the electricity flowed from the transformer to the rails to the engine, but it wasn't exciting enough to maintain my interest, and it was soon dismantled to make room for my radios and electronics.

The basement workshop where I built electronics as a child.

I kept drifting back to electrical things. I would disassemble the telephones in the house to see how they worked. I was curious how a telephone could dial ten different numbers with only two wires, and an older cousin, Dick Stanley, who briefly attended MIT, explained how pulsed dialing worked. I would amuse my friends by dialing the telephone by clicking the hook with my finger rather than using the rotary dials that phones had in those days.

I was puzzled why there were three electrical wires entering the house when there are only two kinds of electricity—positive and negative. My dad, who well knew how to do electrical work, explained that there were really three kinds: positive, negative, and 'shockative.' It took me a while to figure out that he just made that up, and I was soon wiring up electrical devices.

I learned that one can drive two metal rods into the ground a few feet apart and connect them to wires plugged into the wall socket, and it would make worms come to the surface. I would experiment to see what was the optimal distance between the rods to get the most worms. That was fun for a while, and I once used it to collect food for an injured pigeon that I nursed back to health.

I also learned that one could connect the rods to the output of a radio or audio amplifier and pick up the sound with another pair of rods in the ground some distance away and connected to a pair of headphones. I had dreams of setting up my own wireless telephone system using electrical currents in the ground, but I could never get it to work farther than one could shout, and it picked up a lot 60 Hertz hum.

I would build crystal radio sets using a galena crystal with a cat whisker and connect them to long wires strung between the trees to pick up local AM radio stations. Later on, I used the same technology with more modern semiconductor diodes to pick up the signals from nearby ham radio transmitters. I would sometimes connect the antenna directly to a vacuum tube voltmeter to monitor the intensity of local electrical storms, somewhat in the spirit of Benjamin Franklin's experiments with kites. I once connected a long wire to a kite and used it as an antenna, but it was awkward to fly a kite with one hand and work the radio with another.

It was amazing that I didn't electrocute myself since I did things with electricity that no right-minded parent would allow these days. All the radio equipment that I built and modified used vacuum tubes with hundreds of volts, a potentially lethal amount. I was shocked many times and can recall at least twice being knocked to the floor and left tingling for an hour or two, most recently as a graduate student.

Eventually I learned to be more careful when my research involved large capacitor banks charged to thousands of volts. Now almost everyone who works in a physics lab is expected to know CPR, and I've had that training many times but never had to use it, although I watched John Goetz, one of the researchers in our lab administer CPR that quite possibly saved the life of one of our electronics technicians. One of my former graduate students, Kevin Mirus, likes to quote me as having said that 'the problem with kids these days is they haven't been sufficiently electrocuted.' I don't recall making that comment, but it sounds like something I would say, and I half believe it.

When I was young, I didn't have much fear of electricity. On Halloween, my friends and I would go trick-or-treating, but instead of just ringing the doorbell and asking for a treat, we would ring the doorbell and then hide in the bushes waiting for the occupant to come to the door and get a shock when touching the screen door. That was easy to arrange with a six-volt lantern battery, a vibrator, which is an electrical switch that opens and closes sixty times a second to convert dc to ac, and an automotive spark coil, which is a transformer used to produce thousands of volts to fire the spark plugs of a car. Only years later did I learn that this was a bit more dangerous than I had assumed. We would also climb the telephone poles in the neighborhood and unscrew the fuses, extinguishing the street lights for a whole block. Those pranks perhaps bordered on delinquency, but we never really hurt anyone, and we didn't steal or vandalize things.

I did like to follow the telephone repairmen around, watching them work, and I would ask them to give me scraps of wire, often getting whole spools of the wire they strung from the telephone poles to the houses. I would set up my own private telephone systems connecting the house to the garage or to the neighbor's house. Later, when I was a ham radio operator, I would beg them to give me a T-1 microphone button that was in every telephone handset and that worked splendidly as a microphone for my ham radio, and I eventually had a large collection of those. I suppose they thought it was better to give them away than to have them stolen from the phones in telephone booths, which was easy to do before they eventually started screwing them on so tight that one needed a special tool to remove them, which of course we promptly fabricated. I set up an intercom throughout the house, mainly so that I could hear the police and ham radios in the basement from anywhere in the house.

Wiring up the house was an early pastime. I was a firm believer in Santa Claus until an embarrassingly late age, in part because when I was very young, my father awoke me on Christmas eve and told me that Santa Claus was here. We sneaked into the living room and watched him begin to set out the presents. When he noticed us, he sat me on his lap and chatted, saying that he would have to return later after I was asleep. Sure enough, the next morning the usual presents were there. Since he always left me some radio equipment, I didn't have much incentive to challenge his reality, although I suspected a hoax.

One Christmas when I was maybe eight years old, I was determined to settle the matter once and for all. I set up a burglar alarm on Christmas eve with a trip wire and an electric bell by my bed that would wake me if anyone entered the living room. For some reason, I never woke up, and the usual presents were there the next morning, and so I gave up trying to confirm my suspicions. Thus to this day, I have no conclusive proof that Santa Claus is a myth.

Another favorite pastime was crawling through the storm sewers of Memphis. Neil Oakes lived about half a mile away, right across the street from a drainage ditch with two culverts large enough to walk into. With flashlights in hand, we would explore every tributary until the pipes became too small to crawl through, emerging wet and covered with dirt and cobwebs. Aside from a few spiders, we never encountered any animals, although I learned later that racoons like to live in the storm sewers. Fortunately, there was never a flood while we were in the pipes, but I do recall once crawling out through a grate at the edge of the street and giving quite a fright to an elderly woman who was walking nearby. That penchant for crawling through confined spaces re-emerged twenty years later when I did some spelunking in the limestone caves of east Tennessee while working at the Oak Ridge National Laboratory. Unfortunately, Wisconsin has a paucity of interesting caves to explore, and so that hobby is on hold.

A more serious interest was astronomy and space travel. I soaked up all the known facts about the Solar System by reading the encyclopedia and could quote the masses of the planets, their distance from the Sun and the names of their moons. I was less interested in stars since there were so many of them, and I knew that it would be hard ever to travel that far and they wouldn't be hospitable destinations.

I enjoyed reading and watching science fiction, especially television programs like *Twilight Zone* (1959–1964), *Science Fiction Theater* (1955–1957), *Flash Gordon* (1954–1955), *Buck Rogers* (1950–1951), and especially *Tom Corbett, Space Cadet* (1950–1956), but I despaired that travel to the Moon and planets was hundreds of years in the future and that people didn't live that long and thus I would never witness it. Never did I suspect that astronauts would go to the Moon in my lifetime, much less before I finished school and on live television. Perhaps that's why I was so intrigued and excited when the first artificial satellites were launched while I was in high school.

I built a multi-story wooden 'spaceship' in the backyard using lumber and tools from my father's woodworking shop in the garage, and I would sit in it sometimes with friends like Neil Oakes pretending to be in outer space. Of course it was filled with wires and switches and light bulbs and other electrical components, but it never left the ground except in my fertile imagination. That was about the same time my brother was taking me to crawl around in the Memphis Belle. Airplanes interested me, but space travel was my real dream.

Wooden ‘spaceship’ that I built in our backyard.

Despite my many scientific interests, I was only an average student in elementary school (Snowden School in Memphis). In fact I was a bit bored with school, not because it was easy, but because it didn’t excite my interest. There was a lot of rote memorization and little justification for why I should learn it. More often I tried to distinguish myself by being the class clown and annoying the teacher.

That all came to an abrupt end one day in Miss (Lois Claire) Schwamm’s seventh grade spelling class. She was a young and relatively inexperienced teacher, and I didn’t like spelling—it was all memorizing and with few dependable rules, quite the opposite of physics, and to this day I'm a poor speller. I was inciting the other students to be disruptive, and she broke down in tears over her complete loss of control of the class. I decided on the spot that I shouldn't hurt people that way and that it would be better to get serious about my studies, which I did. That was about the time I got my ham radio license. Although I probably would have eventually made that transformation anyway, it does indicate how a teacher can positively affect a student even when seeming to do a bad job. It's a lesson I carried with me into my profession as a physics professor, where I had my share of educational blunders. Miss Schwamm continued her career as a teacher at my high school for at least another five years, but I never told her this story—something I later regretted. My long delayed attempts to contact her were unsuccessful, and I later learned that she died on January 2, 2011 at the age of 90.

By the time I got to high school (Central High School in Memphis), I was a good student, but far from the top of the class. Not surprisingly, I did well in math and science, but only average in English, history, and Latin. I benefitted by the fact that Quent Cassen, my closest friend and ham radio buddy, was a year ahead of me in school and an excellent student. I wanted to keep up with him, especially in mathematics, and he loaned me his books and helped me understand some of the material. As a result, I was always a year ahead in my math class, and the math teacher, Mr. (William) Wharton, whose son Russ was in Quent's class and also a ham, thought I was a prodigy who could do no wrong. In fact, I never learned solid geometry very well, but Mr. Wharton gave me an A anyway. To his delight, I used to type my math homework just to make it a bit more interesting and to reinforce the positive impression he had of me. He used to wait for me along the bus route I took to school, and I would get off the bus and ride the rest of the way to school with him. That nearly got me in trouble when the bus driver complained to the other passengers that I was using a student pass but not getting off at a school, but my Aunt Ruby Young happened to be on the bus that day and came to my defense.

Typing, like home economics, was a class taken only by girls in those days, but I had a feeling it might be useful, and so I 'borrowed' a typing book from school and taught myself to type. One of the motivations was so that I could copy Morse code faster than I could write, but that never worked out very well. Although I could type and copy code in my head faster than I could write, I was not very successful at combining the two skills. Many years later, personal computers came along, and typing turned out to be an essential skill.

In high school, college-bound students took biology, chemistry, and physics in that order. The only thing I recall about biology was having to collect a bunch of leaves from different types of trees and mounting them in a book labeled with their Latin names. That seemed rather silly and pointless, and to this day, I still can't identify many tree species. I think we also dissected frogs, but that didn't make much of an impression either, perhaps because of my earlier experience with frog gigging. I suspect it grossed out most of the girls, though.

Things got a bit more interesting when I took chemistry. For the first time, I was able to use a bit of the mathematics (algebra) that I had learned for something other than ham radio. I think I was the only student in the class who used a slide rule to work out the numbers, which made an impression on the teacher, Mr. (Robert) McCormick, but the lab was a bit too much like my experience with the chemistry set a decade earlier, and there was more memorization than I liked.

By that time, I had decided to go into physics, and so I looked forward to the physics class that the best students took in their senior year, but with a bit of apprehension because it had a reputation for being difficult, and doing poorly could compromise my future. I had already decided to apply to MIT as well as Georgia Tech, and a few lesser schools that I cannot now recall. Getting good grades, especially in math and physics, was very important. Our high school had an excellent physics teacher with high standards, Mr. (J. D.) Simpson, and Quent had warned me what to expect. Unfortunately, Mr. Simpson retired just before my senior year.

The new physics teacher was Mr. (Jimmie) Meeks, and the name fit him well. Although he was reportedly a retired army officer, he was a small, shy, soft-spoken man, apparently with little or no teaching experience, and dare I say without much of a knack for it. He also didn't seem to know much physics, which quickly became apparent when he spent the class hour reading to us from the book and evading our questions, of which I had many. He especially didn't like my questions, because I was a bit of a know-it-all and liked to embarrass him with hard questions. I once recall raising my hand to ask a question, and in a stand-off that lasted at least half an hour until the class ended, I refused to lower my hand and he refused to notice that I had it up.

Our tension had a particularly cruel twist when I did poorly on one of his tests. As best I can recall, the test consisted of four questions, something like asking us to calculate the acceleration of a given mass when subjected to a given force. The questions differed only in the numerical values of the mass and force. I well knew Newton's second law $F = ma$, but in my haste, I carelessly *multiplied* the force by the mass rather than *divide*. Of course I missed all four questions and got a low grade. Mr. Meeks gave me a B in physics for that six-weeks period, which was one of the few grades below an A that I had received in a math or science course in high school, but it did teach me to be more careful. It was the only time I ever complained to a teacher about a grade. His response was to change the B to a B+, but that nearly got me in trouble because he changed the grade directly on my report card, and I had to explain to my homeroom teacher, Miss (Anne) Shewmaker, that I wasn't the one who did it. Fortunately, she believed me and just shook her head and said 'he's not supposed to do that.'

Our war escalated throughout the year. In front of me sat a girl who was having considerable difficulty learning physics. On the tests I would pretend to be looking over her shoulder and copying her answers while Mr. Meeks watched. He knew I wasn't actually cheating since my answers were near perfect and hers were usually wrong. He would just smile and shake his head. I think he finally realized that I was a good student, although once I got to MIT, I was knocked down quite a few notches.

Toward the end of the year, after I had already been accepted to MIT, we had to do a home physics project of our own choosing. By that time I had been a ham radio operator for five years and built countless electronic devices. I decided to build an optical light-beam transmitter and receiver. Realize that this was before lasers and semiconductors. I had to build a vacuum-tube amplifier powerful enough to modulate the intensity of an incandescent lamp, focus the light with a lens and then collect it at the other end with what amounted to a homemade reflecting telescope with a photocell and sensitive vacuum-tube audio receiver. It was a work of art, and I had it sending music over a distance of nearly 300 feet the night before taking it to school. When Mr. Meeks saw it, he scowled and said 'you were supposed to make something, not buy it!' I had done too good a job. He gave me an A for the project, but I'm not sure he ever believed that I wasn't pulling another one over on him.

The last time I saw Mr. Meeks was when I returned to Memphis for the Christmas break of my freshman year at MIT. I decided to show him my physics book, *Introduction to Mechanics, Matter, and Waves* by Uno

Ingard and Bill Kraushaar (Addison-Wesley, 1960), which was written by my teachers specifically for MIT students and was quite a contrast to the conceptual physics book we used in high school. Mr. Meeks thumbed briefly through the book, which was filled with calculus, and said 'this isn't physics; this is some kind of mathematics.' He thought I was still out to get him. Despite the difficulties we had, I might not have succeeded in physics if it were not for my determination to show Mr. Meeks how good I was. It was another example of an inexperienced teacher having a positive impact on a rebellious student.

# Chapter 5

# To God and Back

> You want to know what faith is? Faith is when you believe something nobody in their right mind would believe—that's what faith is! —Archie Bunker
>
> I'm still an atheist, thank God. —Luis Bunuel

At 3 pm on September 8, 1960, I began a new phase of life when I arrived in Cambridge, Massachusetts after a four-day drive with Doug McCallum, the only other student from Central High School in Memphis who enrolled at MIT that year. Doug was a better student than I was, and he was one of two cadets who outranked me in ROTC. His brother Charles had just graduated from MIT, and so Doug knew the ropes, having visited his brother and gotten good advice, but he didn't share my interest in radio and electronics. A third student from Memphis, Ron Gilman, a ham radio friend, also enrolled at MIT that year, but he was from a different high school and was rather more independent, and I rarely interacted with him again, although he went on to be a successful attorney, judge, and member of the United States Court of Appeals. Doug followed in his brother's footsteps and joined the same live-in fraternity, while I moved into nearby Burton House, the undergraduate dormitory where I spent the next four years.

Burton House was one of several old dormitories that stretched along the banks of the Charles River about a ten-minute walk from the main building at MIT where classes were held. It was a five-story building populated by undergraduates who were not accepted by any of the fraternities or were not interested in communal living. My room in the rear of the dormitory faced the athletic fields across from which was a Heinz factory that must

Burton House, the dormitory at MIT where I lived for four years.

have made 57 Sauce since it sported a large '57' sign that is imprinted on the brains of a whole generation of MIT students. Not far away was a Nestle Chocolate factory whose delightful aroma wafted through the campus during my whole four years at MIT and perhaps contributed to my lifelong addiction to chocolate.

It was a new and different experience for me. I had never been away from my parents for more than a few days at a time, and my Uncle Sterling Stanley, whose son Dick had briefly attended MIT, predicted that I would soon be homesick and return to Memphis. I was assigned a room with three other freshmen roommates. One was Jewish with a wife and young child that he had left behind in Long Island, NY, another was also from New York and a proclaimed atheist, and the third was from Bellingham, WA and claimed to be a communist. This was quite a shock for one who grew up in the buckle of the Bible Belt, where we had more churches than gas stations and during the height of the Cold War. But all three of them were extremely bright, and we spent many hours talking, often late into the night. We discussed the physics, chemistry, calculus, and humanities courses that all freshmen took, but also many other topics. I'm sure they considered my beliefs as odd as I did theirs, but they were always willing to discuss and debate, and they were more curious than judgmental. While getting a fast-paced education in science, I was also getting an important education in the broader issues of life through those discussions.

It was the height of the civil rights movement, but its effects had yet to reach me. The schools and churches and almost everything else in Memphis were segregated, and 'separate but equal' was the mantra. We had the 'separate' part down well, but the 'equal' was sorely lacking. There were separate drinking fountains and restrooms for 'white' and 'colored,' and the colored were expected to ride at the back of the bus, which they obediently did in my experience. My parents, like almost everyone else I knew in Memphis, were staunch segregationists, and I paid little attention to news reports of the protests that were beginning to occur. I was taught that the races shouldn't intermingle, and that blacks, or 'Negroes' as we innocently called them in those days—though not with that pronunciation—were to be servants and to do other menial work. We had a black maid who came once or twice a week to do the housework and was paid three dollars a day plus carfare (25 cents to ride the bus), and my father employed a black delivery man at his office supply business.

My roommates suspected that most white southerners were sympathetic to the Ku Klux Klan, if not actual members. While some surely were, I didn't know any such people and was only vaguely aware of the organization. My arguments centered around persuading them that most whites were kind to blacks, and meant them no harm, much as one would treat a pet, which in retrospect was a telling analogy. I cited instances where my mother had given our maid rides in her car—although she had to sit in the back seat—and when my father gave extra money to his 'delivery boy' and excused his laziness and incompetence. I recall my father once saying if he were ever lost in the woods, he would 'want to be in the company of a Negro.' Even professional sports players were mostly white in those days.

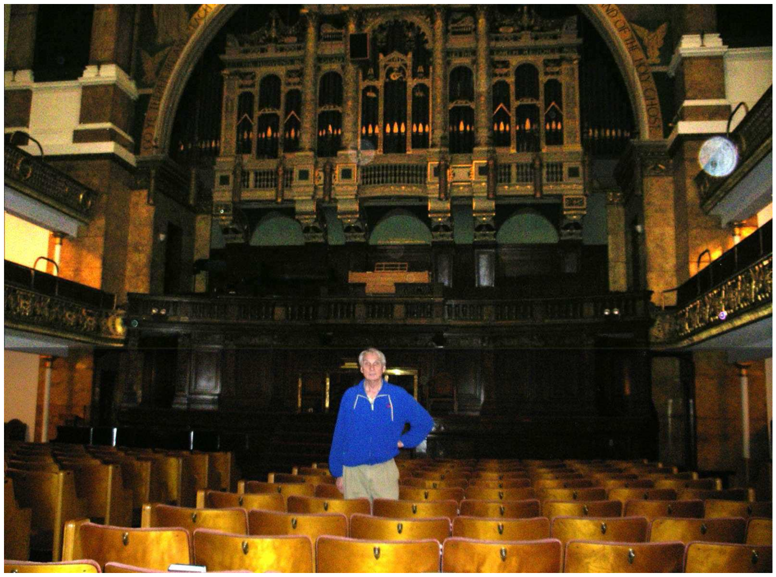
I wasn't getting very far defending my stereotypes and beliefs. I finally resorted to what I thought was an unassailable argument, which had seemed so reasonable when I heard it from my father and others as a child. I asserted that if we segregate the schools, soon there will be intermarriage. One of my roommates said 'yes, so?' I had lost the debate and had to reconsider my views. It helped that MIT was a rich cultural community, including a few blacks and providing my first exposure to Asians. That transformation was complete when I was able to proudly support the election of the first African-American president in 2008 and marry an Asian in 2010.

The racial discussions paled in comparison to the religious debates. I was brought up in a culture where everyone believed in God and most were Christians except for a few Jews. I had attended Union Avenue Methodist Church with my parents all my life, and my father taught Sunday School. I had little interest in it but attended out of obligation and tradition except on those occasions when we spent the weekend at our cottage on Pickwick Lake or when there was a ham radio contest and my parents let me stay home on Sunday morning. My friends all had similar experiences. I could not imagine anyone admitting not to believe in God since that would imply they had no morals, and it would be the ultimate blasphemy. Religion was a part of life, and I never thought to question it, but I didn't pray or read the Bible outside of church, and I thought little about it.

My roommates were intrigued by my views and challenged me to defend them. I was completely at a loss, since I had never been confronted in that way, but I felt strongly that I was right and they were wrong. I was not going to deny the existence of God even though I could not think of a single good argument in support of my beliefs, and they had obviously thought more about it than I had. I felt lost and isolated and decidedly out of tune with their rational thinking.

Then one day another student knocked on my dormitory room door and invited me to join a small group of Burton House residents to attend Tremont Temple Baptist Church in Boston, which I later learned was the first racially integrated church in America. It was a bit more evangelical than my Methodist church in Memphis, but the rituals and hymns were familiar, and I had finally found some kindred spirits. It was possible to be a student at MIT and be a Christian!

But I still had a long way to go to develop arguments for my beliefs that were defensible to rational-minded MIT students. I attended church regularly and began to socialize with my new Christian friends, especially my upperclass mentors like Terry Langendoen, Danny Thornhill, and Don Baker who lived in my dormitory. I attended Bible studies and meetings of the United Christian Fellowship (UCF), the MIT chapter of Intervarsity Christian Fellowship (IVCF). Within a year, I was holding my own in discussions with non-Christians, and I was put in charge of evangelism for the whole campus in my junior year and became president of UCF in my senior year. Along the way, I became involved with Campus Crusade for Christ, an evangelistic organization, and the Navigators who developed follow-up materials for the Billy Graham crusades, spending the summer of 1962 at their headquarters in Colorado Springs as Terry and Don had done in the preceding two sum-



Tremont Temple Baptist church that I attended while at MIT and that funded my summer in Brazil.

mers. Terry arranged for me to spend the summer of 1963 in Brazil as he had done the year before, participating in the missionary work of the international wing of IVCF under the guidance of Ruth Siemens, a remarkably congenial and energetic woman, whose death at age 80 on December 20, 2005 saddened me.

I believed in a personal God who cared about me and directed my daily life. I read the Bible every day, prayed, and interpreted the events of life as God speaking to me. I counseled at youth evangelistic crusades, visited the rescue missions in Boston, and attended weekend retreats sponsored by my church and by the Navigators. I developed a logical message palatable even to many MIT students of how God created the world, brought man into it, how we are sinful and unacceptable to a perfect God, how He sent His son Jesus Christ to the Earth to die as payment for our sins, and how we need to accept Him as our savior. I spent a lot of time trying to persuade others at MIT and elsewhere to accept this message, mostly without effect but with occasional success among those who were already predisposed to it as I had been.

Those activities consumed a large portion of my life and detracted from the science education I was getting in parallel and limited my options upon

Me (at far right) with missionary families in Brazilia, Brazil in 1963.

graduation. I passed all the required courses but with only mediocre grades, and so I briefly considered abandoning science and enrolling in the nondenominational evangelical Dallas Theological Seminary. However, I applied to a number of second-tier graduate schools, the best of which was the University of Wisconsin where I was accepted but without financial support, thanks to the associate chairman Connie Blanchard who decided to take a chance on me. After spending the summer of 1964 working in the Cosmic Ray Laboratory at MIT under the supervision of my senior thesis advisor, Alan Lazarus, I enrolled at Wisconsin on academic probation and quickly found a position in the plasma physics group by impressing its leader Donald Kerst with the electronics skills I had developed a decade earlier as a young ham radio operator.

My arrival in Madison in September of 1964 marked the beginning of a new and rather different phase of my life. My attention turned much more narrowly to physics and the pursuit of a PhD. I still struggled in my graduate courses and had to work hard to barely pass the qualifying and preliminary examinations, but I was comfortable and productive in the laboratory. I rebuilt much of the electronics and enjoyed collecting and analyzing experimental data and writing up the results. Unlike at MIT, where I felt that almost everyone was smarter than me, I began to develop more self-confidence and was among the best of the graduate students in the lab. I made up for my lack of academic abilities by working harder than most of the others.

I still had religious views, and I explored the campus chapter of IVCF only to find it less vigorous than the MIT chapter whose president I had just been, and it was dominated by undergraduates. The recommended Faith Baptist Church in Monona was a disappointment compared with my church in Boston. When I joined the church, I was asked to accept their creed, which among things said that they believed the Earth was created in six days. I was a conservative Christian, but I was enough of a scientist to know that wasn't true, and the issue had never come up in my previous church. The pastor told me not to worry about that detail, but it was the start of a slide away from the beliefs that I had held so firmly.

I had no close evangelical Christian friends, and I began attending church less frequently, deriving my satisfaction from the physics that was increasingly exciting. Although I was occasionally questioned about my beliefs, I did not have vigorous discussions on the subject as I had at MIT, and I didn't feel the need to defend my beliefs, much less proselytize others. In essence, I felt that I had outgrown the need for the kind of emotional and philosophical crutch that Christianity had provided during my transition into adulthood.

For the next forty years, I attended church only on rare special occasions and deflected questions about my belief in God with complicated and somewhat evasive answers. I later came to understand that I was a pantheist. Like Albert Einstein, I did not believe in a personal God who interacted with people or altered the course of nature, but I was willing to use the term 'God' as a synonym for nature itself, although I rarely did so. In essence, physics had become my God. Its story of creation (the Big Bang) was much more compelling than the biblical story, and it is supported by considerable evidence in contrast to the stories in the Bible, which I had already accepted as allegorical. I would explain to evangelical Christians that my God was much more powerful than theirs since mine created the Universe in a fraction of a second rather than in six days.

Much of the rest of Christianity stuck me as superstitious and unscientific, and I could not see any evidence that Christians were any better or happier or smarter than the nonreligious scientists I had come to revere. Furthermore, I realized that religious fundamentalism was the cause of most of our wars, including many of the 'noble wars' fought by predominantly Christian nations. I had to admit that my religious views were almost entirely a result of my upbringing, and that if I had been born in an Asian or Muslim country, I would almost certainly have different views, and my views were no more defensible on rational grounds than theirs.

Then in 2007, I read *The God Delusion* by Richard Dawkins. I found myself in agreement with almost everything he had to say, and he gave voice to what I had come to believe. Furthermore, he argued that being a pantheist is a cop-out since many religious people misinterpret that as a belief in their God and that it is more accurate and honest to admit to being an atheist, which I have done ever since. What I once considered an unthinkable blasphemy, I now regard as a badge of intelligence and thoughtfulness.

I am still in awe of the known facts about the Universe and how it was born, but I do not see the need to anthropomorphize the forces of nature or attribute supernatural powers or special status to Jesus Christ. As with so many things, the great physicist Richard Feynman put it succinctly by saying that 'the stage is too big for the drama'—to which I fully concur.

# Chapter 6

# Plasma Physics and Controlled Fusion

> There is not the slightest indication that nuclear energy will ever be obtainable. —Albert Einstein, 1932

My childhood scientific interests were mainly in electricity, radio, astronomy, and space travel. Thus it was natural that when I got to MIT, I most enjoyed the laboratories and the courses in electronics. I might have gone into electrical engineering, for which I had some talent, except that I had long wanted to be a physicist in the mode of those who unlocked the mysteries of electromagnetism, discovered the ionosphere, developed the atomic bomb, and launched satellites into space. And I wanted to follow in the footsteps of my idol Frank Dietrich and prove to Mr. Meeks how good I was.

I was only a mediocre student, but that is more a comment on the high quality of my peers than on my abilities. I did not realize until I was well along at MIT that I had been admitted through a regional distribution program in which students from areas of the country with inferior schools were preferentially treated. Someone with my grades and scores on the admission exam from New York or Massachusetts would never have been admitted. From the start, I was under-prepared for the courses, and I only fell further behind as the courses became more advanced. I especially had trouble with the humanities courses that all MIT students were required to take, and it was only because of help from Doug McCallum that I was able to pass them. However, very few students flunk out of MIT, although some leave because they don't like to work so hard. With persistence and determination, anyone who was admitted can graduate from MIT. I learned an important lesson for life – that hard work and perseverance can substitute for innate ability and skills.

MIT was a wonderful place to be. The faculty and students were uniformly excellent. They worked us hard and expected much of us. I encountered many famous scientists or ones who would later achieve fame. My academic advisor was a fortyish Professor Henry Kendall, and every semester I would stop by his office to have him approve my courses. I never spoke with him about anything else, but years later he was awarded the 1990 Nobel Prize in Physics for work he did during my undergraduate years providing the first evidence for quarks. I had an electrical engineering course from a young Amar Bose, who went on to found the Bose Corporation and become a billionaire. One evening while I was having dinner in the dining hall of our dormitory, Harold Edgerton, the father of stroboscopic photography and co-founder of the company EG&G sat down beside me and began talking about his adventures. I could continue with many other examples.

MIT students were expected to do a thesis project in their senior year, and I ended up in the Cosmic Ray Laboratory, which was a part of the Laboratory for Nuclear Sciences, working under the supervision of Professor Alan Lazarus, a young, personable assistant professor who was a great teacher and compassionate mentor, but was ultimately denied tenure. The first artificial satellites had been launched only six years before, and interesting new data on the ionosphere, the solar wind, and the high energy particles (cosmic rays) bombarding the Earth from an unknown source were being collected from those early satellites. The Van Allen radiation belt had only recently been discovered.

I was asked to develop an acoustic spark chamber capable of flying in a satellite. A spark chamber is a device with a pair of parallel metal plates (like a capacitor) across which several thousand volts are applied. When a cosmic ray passes through the device, it leaves behind a trail of ionized (electrically conducting) gas, and a spark occurs along the path of the track. The task was to develop a means for determining where the spark had occurred by listening to its sound with several microphones placed around the edge of the plates using the time of flight of the sound. It's a bit like how the GPS system works, but with sound waves rather than radio waves and with the source and detector of the waves interchanged. It was an ideal project for me, because the physics was simple, most of the work was electronic, and it involved space flight. I successfully completed the project, although I don't think it ever flew in space. I spent the last few months of my senior year installing the microphones I had developed in a large spark chamber at the Cambridge Electron Accelerator on the Harvard campus under the direction of Professor Lou Hand. I don't know whether they were ever used either.

It was while working alone in that lab on November 22, 1963 that I learned of the assignation of John F. Kennedy when someone came into the room and asked if I were so isolated that I had not heard the news. They say one always recalls where one was and what one was doing when such a major event occurs.

Professor Lazarus must have been impressed with at least some of my skills since he wrote a letter of recommendation that helped get me admitted to graduate school, although he once suggested that I might do better as an engineer than as a physicist. He recommended that I apply to Wisconsin, a school about which I knew almost nothing. He hired me to work for him during the summer of 1964 after my senior year and before leaving for Wisconsin.

The summer job I was given was to develop a beam of protons. The idea was to pass an electron beam through hydrogen gas where some of the electrons knock other electrons off the atoms of hydrogen. The resulting protons would then be attracted to a negative electrode with a hole in it to produce a weak ion beam. Most of the work involved learning about vacuum systems and developing the required electronics, which exploited my electronic skills and provided important lessons of use later in graduate school. The project was a success, although the beam current was never large, and I'm not aware that the device was ever used for anything after my departure. I wrote up the results on my own initiative, and I can recall Prof. Lazarus commenting that I had now written two scientific documents. That was probably the start of my love for scientific writing.

Students who are admitted to graduate school in physics are usually offered some form of financial support, either a fellowship, or a teaching or research assistantship. Marginal students are sometimes accepted without financial support, but they rarely enroll. Thus it must have been a surprise to the Wisconsin physics administration when I appeared at their doorstep in September of 1964. In retrospect, it was a gutsy move since the only money I had was the thousand dollars I had saved working that summer at MIT and five hundred dollars from my parents, which they said was their last gift after funding my undergraduate education. But it was enough to pay tuition for the first semester, a room in the dormitory, and a meal plan.

With confidence in my laboratory skills and a certain cockiness from having graduated from MIT, I set out to convince someone on the faculty to hire me. My first choice would have been space physics since that seemed closest to the work I had done at MIT and to my interests, but there was no such program in the Physics Department at the time. A second choice was high energy physics (also called particle physics), a field that involved studies of the same particles that occur in cosmic rays but produced in large particle accelerators. It was the largest and most active group in the Department, and I talked to many of the ten or so experimental faculty in that area, only to be given various reasons why they could not hire me. Someone suggested I consider plasma physics, which was a new and active program in the Physics Department, but involving only a single experimental faculty member. I knew very little about plasmas, and it seemed like a difficult and not very interesting subject. But I needed a job.

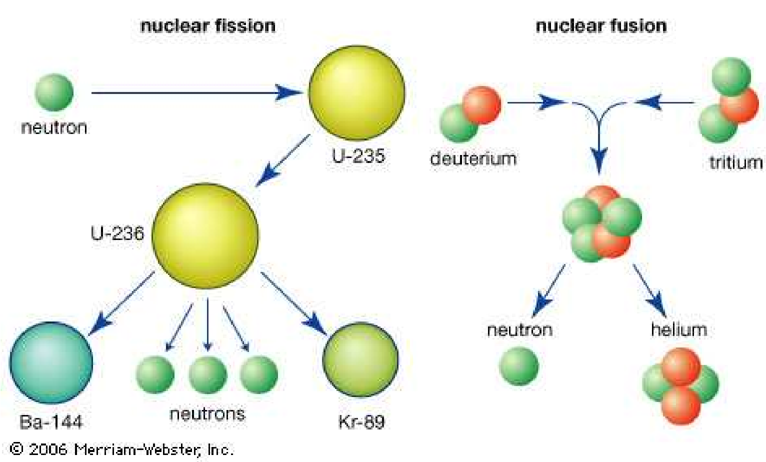
My life changed forever when I knocked on the door of Professor Donald Kerst, the head of the plasma group. He was looking for someone to develop circuits to amplify the signals from electric probes in the plasma confinement device that he had invented and just constructed on campus. It was not hard to convince him that I had the needed skills, and he hired me on the spot and put me to work. Indeed, it was a perfect job for me, and I quickly impressed him with my electronics knowledge and laboratory skills.

I began to learn a bit about plasma physics. It was not at all what I thought. A plasma is an electrically conducting gas, and so it was a natural and easy extension of my electronic interests. It is also the constituent of the ionosphere, the medium that enabled my long-range amateur radio communications as a teenager, and it resembles the solar wind that was being studied in the Cosmic Ray Lab at MIT. The plasmas that we were creating in the laboratory were similar to the solar corona. Since interstellar space is filled with a low density plasma, it also tied in with my interests in astronomy. I learned that the motivation for the research was to produce a new and potentially unlimited source of energy by fusing together light isotopes of hydrogen, much as in a hydrogen bomb, but in a controlled fashion. The energy source is the same as that in the stars. This was exciting stuff!

Coincidentally, a year after I joined the plasma group, our Department hired Bill Kraushaar and Frank Scherb, both of whom had been my teachers at MIT and had worked in the Cosmic Ray Lab where I did my senior thesis. They started a space physics program at Wisconsin and began hiring students. I would almost surely be a space physicist now if they had arrived a year earlier or me a year later, but I was happily immersed in plasma research by then. I did take graduate courses in space physics from both of them and saw the many connections between what they were doing and my work in plasma physics.

Bill Kraushaar taught the first physics course I took at MIT and the last physics course I took at Wisconsin, and he was the Chair of the Physics Department when I began my career as a professor. Recall that he was also a coauthor of the physics textbook that I used as a freshman at MIT and that my high school physics teacher, Mr. Meeks, thought was some kind of mathematics. He was the only physics faculty member at Wisconsin other than Don Kerst who was a member of the prestigious National Academy of Sciences. It saddened me when he died on March 21, 2008 of Parkinson's disease at age eighty-seven.

The connection of plasma physics to the production of energy by controlled nuclear fusion deserves some explanation. Most people know how nuclear fission was developed in the Manhattan Project at Los Alamos during World War II and was used to produce the atomic bombs that ended the war in 1945 when two such weapons obliterated the Japanese cities of Hiroshima and Nagasaki. The first hydrogen bomb, using the fusion process and vastly more powerful, was detonated in 1952 and set off the nuclear arms race and the era of 'mutually assured destruction' (MAD). The first nuclear fission power plant began producing electricity in 1960, and most scientists assumed that fusion would also be harnessed to produce power within a short time.




Nuclear fission contrasted with nuclear fusion.

Fission and fusion are sometimes confused, but from the physics standpoint, they could hardly be more different. In nuclear fission, heavy elements such as uranium or plutonium capture neutrons and split into two or more lighter elements with the release of additional neutrons, leading to a chain reaction. By contrast, in nuclear fusion, isotopes of the light elements such as hydrogen or helium are fused together, producing heavier elements. In both cases, energy is released through the conversion of mass into kinetic energy of the reaction products (primarily the neutrons) through the famous formula $E = mc^2$.

Some people assume that the conversion of mass into energy is unique to nuclear reactions, but the same process occurs when fossil fuels are burned, albeit on a much smaller scale. Fusion converts about 1% of the fuel's mass into heat, whereas fission converts about 0.1%, and chemical processes (combustion) typically convert only a billionth of a percent of their mass into heat, far too little to measure directly. There are processes that convert 100% of their mass into radiative energy, such as the annihilation of a particle by its antiparticle, but no one has any idea how to use such reactions as a large-scale power source, and antimatter is not naturally occurring on Earth in adequate quantities, and it requires at least as much energy to produce as would be released in the reaction.

The fusion process produces about ten times more energy than does fission for the same mass of fuel, and the fuel is much more abundant, in the simplest case consisting of deuterium, a naturally occurring isotope of hydrogen having a neutron in addition to a proton in its nucleus. Every gallon of ordinary water contains about an eighth of a gram of deuterium, which can be easily extracted and has the same energy content as 300 gallons of gasoline if used to fuel a fusion reactor. Furthermore, the process is relatively safe, and it produces much less radioactive waste than a comparable fission reactor.

The problem is that whereas fission involves the interaction of an uncharged neutron with a positively charged nucleus, fusion requires the interaction of two positively charged nuclei. There is a force of repulsion between electric charges of like sign, and so it is difficult to make the fusion reaction occur because of this so-called 'Coulomb barrier.' While fission will occur at room temperature, the fuel of a fusion reactor must be heated to a temperature of about a hundred million degrees Celsius to give the nuclei sufficient energy to overcome the Coulomb barrier. This high temperature is obtained in the hydrogen bomb through an initial fission explosion. In a controlled fusion reactor, other heating methods must be used, but the more serious problem is to find a way to confine the hundred million degree reacting fuel at sufficiently high densities and for a time long enough for the nuclear reactions to occur,[1] not because it would melt the walls of its container, but because it would instantly cool to temperatures at which the reactions would cease if it contacted the walls. Therein lies the connection to plasma physics.

At sufficiently low temperatures, most substances become solid (water becomes ice). As the solid is heated, it will typically melt, forming a liquid. As the liquid is further heated, it becomes a gas (water becomes steam). These are the three states of matter familiar to most people.

However, when a gas is heated sufficiently, usually to a temperature of a few thousand degrees, some of the electrons are stripped from the atoms, forming a fourth state of matter called a 'plasma.' As the temperature increases further, typically around a hundred thousand degrees, essentially all the atoms have lost at least one of their electrons, forming a 'soup' of positive ions and negative electrons, and the plasma is fully ionized. Since it consists of electrically charged particles rather than neutral atoms, a plasma is electrically conducting, in contrast to an ordinary gas. It has been estimated that upwards of 99% of the visible matter in the Universe[2] is in the plasma state. In particular, the stars are balls of plasma undergoing slow thermonuclear fusion. The Earth is an unusual place in which the other three states of matter exist in abundance and in combination. Plasmas are relatively rare on Earth but occur in the ionosphere, the aurora, lightning bolts, fluorescent lamps, and increasingly in high definition television displays.

During the height of the Cold War in the 1950s, research on controlled nuclear fusion was classified because it was assumed that success would soon be achieved, and one application would be to use the neutrons to convert uranium into plutonium and to provide a source of tritium (an isotope of hydrogen with two neutrons in its nucleus) for thermonuclear weapons. Major programs were underway under the veil of secrecy in the United States, primarily at Los Alamos, the Livermore National Laboratory in California, the Oak Ridge National Laboratory in Tennessee, and Princeton University in New Jersey under the code name of 'Project Sherwood,' as well as in the United Kingdom and the Soviet Union.

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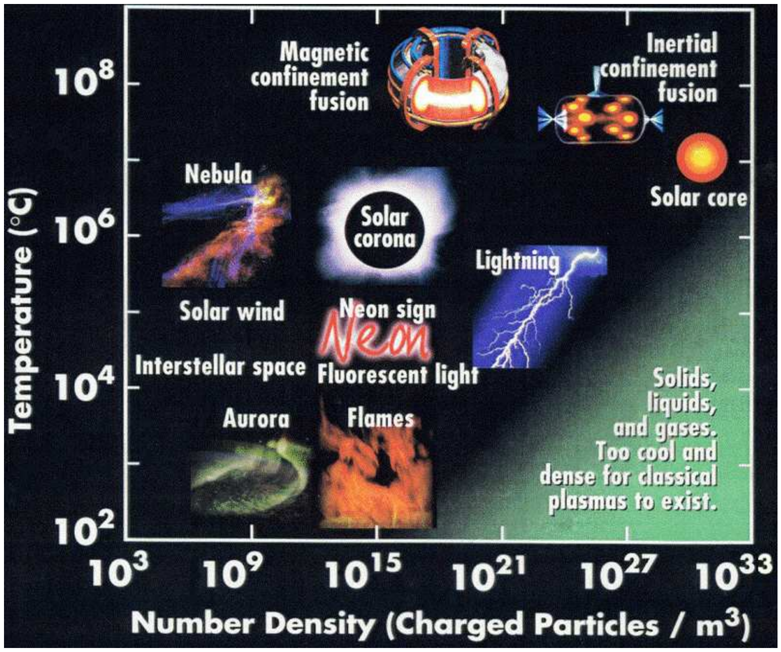
[1] The required density $n$ and confinement time $\tau$ must have a product in excess of about $10^{20}$ seconds per cubic meter according to a criterion first calculated by John Lawson in 1955, and known as the Lawson criterion.

[2] This ignores the 'dark matter' that makes up 83% of the matter in the Universe and whose composition is unknown and currently under intense study.




Examples of plasmas in nature and in the laboratory.

By 1958, it had become apparent that the problem was much more difficult than anticipated and that it had limited military use, and thus the program was declassified, at which time a strong international collaboration began that continues to this day with the inclusion of most industrialized nations. The emphasis had turned from a crash program to produce controlled nuclear fusion to understanding the underlying physics that rendered it so difficult. Thus the field of plasma physics was born with the involvement of universities who began training a whole generation of students, of which I was among the first.

The stars confine their burning plasma with a gravitational field, but the gravity of the Earth is much too small to be of use. The most promising idea for confining a hundred million degree plasma in the laboratory is to use a magnetic field, made conveniently possible by the fact that the plasma is electrically conducting. It also offers a means for heating the plasma since an electric current passing through a conductor causes it to heat (ohmic heating).

The main problem is that a multitude of instabilities occur in such a magnetically confined plasma that in the earliest devices caused it to escape a million times faster than required to achieve controlled fusion. Many devices were proposed, built, and tested, and they all performed poorly. A detailed theory of magnetized plasmas was lacking, and the devices were constructed based mainly on intuition and trial and error. These devices had features in common with particle accelerators like the cyclotron, betatron, and synchrotron, which also use magnetic fields to confine their beams of energetic particles.

My physics mentor and graduate thesis advisor, Don Kerst, was an early accelerator designer and inventor of the betatron, but he was deflected to work on the Manhattan Project during World War II. At the end of the war, he resumed his work on particle accelerators at the University of Illinois until 1953 when he returned to Madison where he had been a graduate student to head the Midwest University Research Association (MURA), an organization of midwest universities dedicated to accelerator development.

He continued to follow with interest the development of controlled fusion, and in 1957 he took a position as head of the experimental fusion program at General Atomics (GA), a division of General Dynamics in San Diego founded in 1955 for the purpose of harnessing the power of nuclear technologies. It was while at GA that he, along with Tihiro Ohkawa, developed the idea for the toroidal multipole plasma confinement device that was ultimately built after he returned to the University of Wisconsin in 1962 and on which I did my PhD thesis and earned my credentials as a plasma physicist.

# Chapter 7

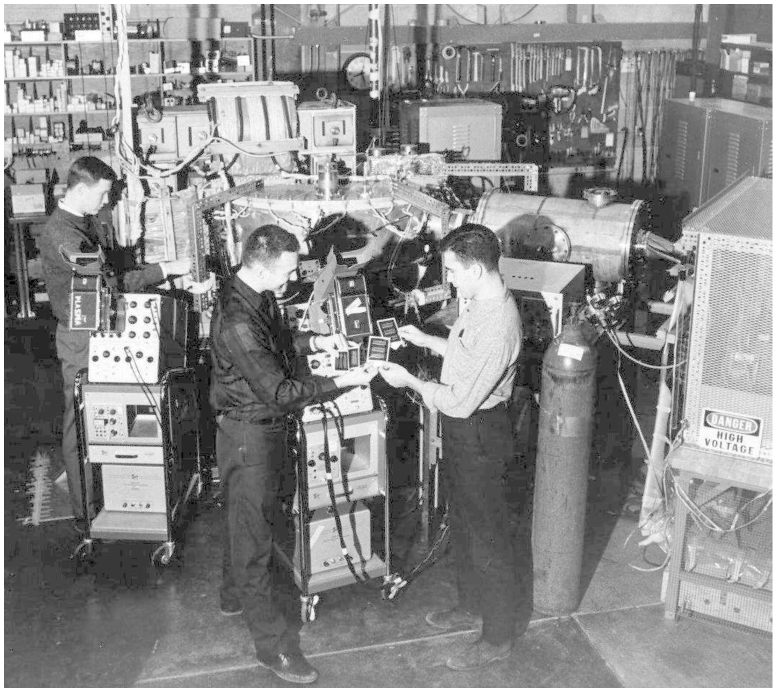
# Multipoles, Mirrors, and Microwaves

> Physics is like sex. It may have some practical use, but that's not why we do it. —Richard Feynman

My arrival at the University of Wisconsin in September of 1964 was the start of a career in plasma physics, which dominated my scientific efforts for the next twenty-five years. I cannot possibly do justice here to all that occurred during those years, but I will mention some of the highlights and turning points that preceded the shift in my interests that occurred in 1989, trying not to become too technical.

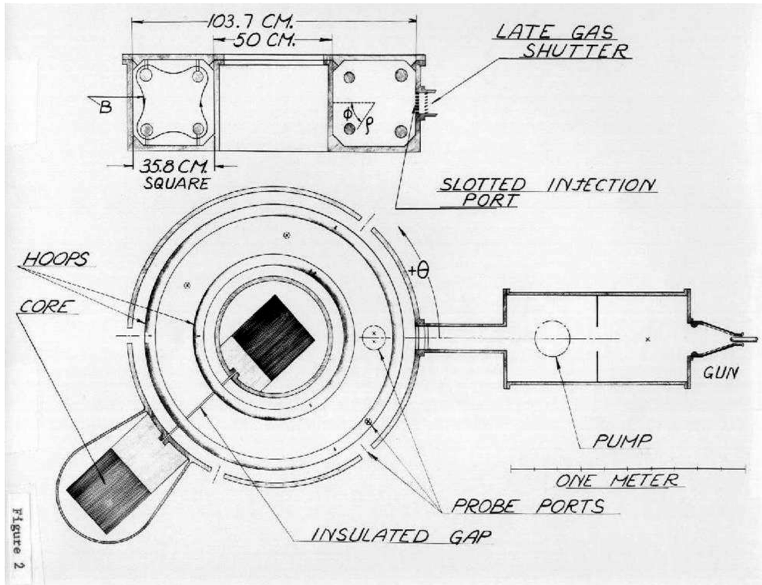
The Toroidal Octupole had been under construction for about a year when I arrived in Wisconsin, and it was just beginning to produce data. Working on the device was a postdoc, Walt Wilson and graduate students Dale Meade, Cliff Erickson, John Schmidt, Don Lencioni, and Bob Therman. We all shared an office in 'the Barn,' a high-bay building amidst the experimental farms on the far west end of the campus, designed for the construction of hydrogen bubble chambers used by the high energy physicists. I recall the explosion-proof telephones and the roof that was supposed to blow off in one piece in the event of an accident, which fortunately never occurred, although there was a minor incident that caused a large metal plate to come crashing down onto the desk of Stephanie Fassnacht, a high energy physics graduate student whose postdoc husband Robert was killed in the 1970 bombing of Sterling Hall toward the end of the Vietnam protest era. The high energy group working there under the direction of a young assistant professor, Lee

Pondrom, was constructing much less dangerous spark chambers, which were larger versions of the device I had worked on as an undergraduate at MIT.




John Schmidt, me, and Don Lencioni taking data on the Toroidal Octupole in about 1967.

The Toroidal Octupole was basically a large transformer with a five-ton iron core, a capacitor bank consisting of about a dozen 240-$\mu$F, 5-kV capacitors, each weighing several hundred pounds, and a secondary consisting of four copper hoops, each about the size of a hula hoop but much heavier, near the corners of a toroidal (doughnut-shaped) vacuum vessel with a square cross section. The individual components were all familiar to me but on a much larger scale than I had previously encountered. About once a minute, the capacitor bank would discharge into the 60-turn primary of the transformer, producing a current of about 200 kiloamperes in the copper hoops, creating an octupole magnetic field for about five milliseconds. Near the peak of the magnetic field, a hydrogen plasma was injected into the field from a plasma gun, which was essentially an enormous spark plug. After a brief turbulent period, the plasma smoothly decayed over the next millisecond, which turned out to be a very long time compared to the other plasma confinement devices that had preceded it in which the plasmas were turbulent and escaped in a few microseconds.

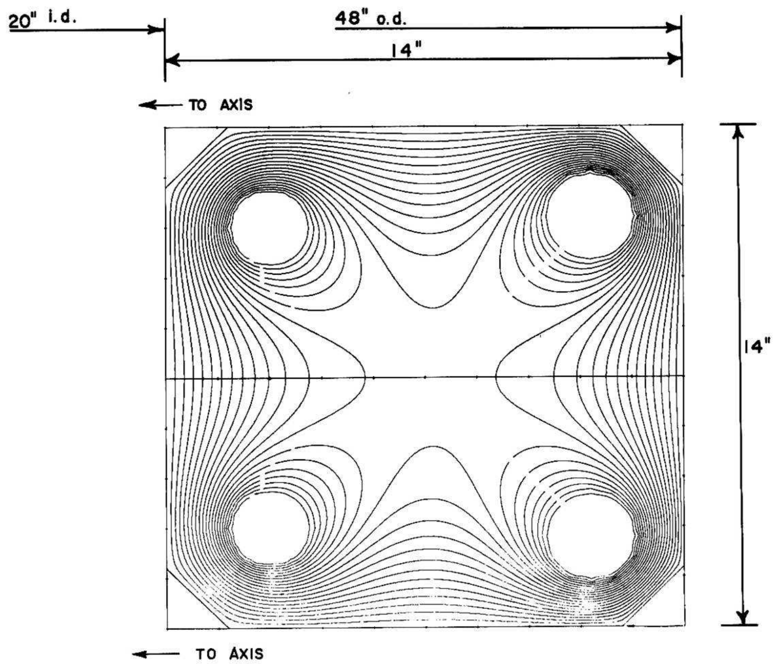



Schematic of the Toroidal Octupole device.

The key ingredient of the device was the novel shape of the magnetic field. Unlike a piece of iron, which is ferromagnetic and thus attracted to a magnet, a plasma is diamagnetic and is repelled by a magnet. Thus a plasma has a natural tendency to escape from the magnetic field that confines it unless one can arrange for the magnetic field to be stronger near the walls of the device than in the interior where the plasma resides. Unfortunately, Maxwell's equations of electromagnetism preclude such a field in a vacuum except in an average sense. The Toroidal Octupole was the first such 'minimum average $B$ device,'[1] and it suppressed the instabilities that had plagued all previous plasma confinement devices.

When Don Kerst reported the results at the International Atomic Energy Agency Conference on Plasma Physics and Controlled Nuclear Fusion Research at Culham, England in 1965, it was an instant sensation. Over the next few years, every major fusion laboratory around the world had built a

[1] $B$ is the symbol universally used to denote a magnetic field, a vector with a magnitude and direction. More precisely the plasma resides in a region where $\oint dl/B$ is maximum, where the integral is along the length of the closed magnetic field line.




Toroidal Octupole magnetic field showing minimum average $B$ configuration.

toroidal multipole (dipole, quadrupole, octupole, etc.). Distinguished scientists from those labs visited Wisconsin to see our device and learn how it worked. Don Kerst allowed the graduate students to show them the machine and describe its operation, and I found myself explaining technical details to many of the leading scientists in the field. Kerst also let the students present papers at conferences, and the leaders of all the major laboratories were in the audience, listening intently and asking probing questions. For the next forty-three years I never failed to attend the annual meeting of the Division of Plasma Physics of the American Physical Society. Kerst told us to enjoy the attention we were getting because it would not always be like that, and indeed, within about five years, the tokamak came along, and the interest in toroidal multipoles faded as rapidly as it began.

My PhD thesis involved heating the plasma with microwaves, much like one would cook a turkey in a microwave oven. The process is called electron cyclotron resonance heating (ECRH) since it deposits the energy in the electrons using a frequency equal to the natural frequency at which electrons orbit the magnetic field.[2] It was a project suggested not by Kerst,

[2]In a typical magnetic field of 1 kilogauss, the electron cyclotron frequency is about

but by a rather remarkable undergraduate student named Paul Nonn who was working in our lab and had experimented with microwaves during his teenage years, much as I had done with ham radio. Paul had collected a large assortment of military surplus microwave gear, primarily magnetrons, waveguides, pulse-forming networks, and other components mainly used for high-power pulsed radar. He taught me about microwave technology and helped assemble the necessary equipment. His brother, Bo, along with Tom Lovell, were other undergraduates working in our lab, and they helped me assemble the electronics to power and control the magnetrons. That radar endorsement I had gotten on my commercial radiotelephone license just for the fun of it back in high school had finally come in handy. The method worked beautifully and produced a hotter or denser plasma (but not both at the same time)[3] than we were able to achieve with the plasma gun.

I defended my thesis in May of 1969 and became a PhD. It was the culmination of everything I had worked toward and the fulfillment of a dream. I was never so proud or stood so tall. I had an interesting reaction my first evening as ‘Dr. Sprott.’ To relax, I walked down State Street and around the State Capitol building. It was a lovely but warm summer evening, and many people were walking about. Somehow, I thought they should have noticed the new doctor in their midst, but they walked right past just as they had done the day before. They say there is such a thing as ‘post PhD depression.’ I can’t say I became depressed, but it was the start of accepting that I was the same person as the day before and that now I had to do something with all the education and training I had received.

I continued on for the next year working in the same lab as a postdoc, extending my studies to ion cyclotron resonance heating (ICRH), which required a frequency 2000 times smaller, around 1 MHz, right in the middle of the AM broadcast band, and employed techniques that were a direct extension of my ham radio experience. I built a 100 kW pulsed oscillator and used it to heat the plasma.

I also helped with the finishing stages of construction of the Levitated Octupole, a second generation octupole device that Kerst had designed and built at the Physical Sciences Laboratory (PSL), thirteen miles off campus

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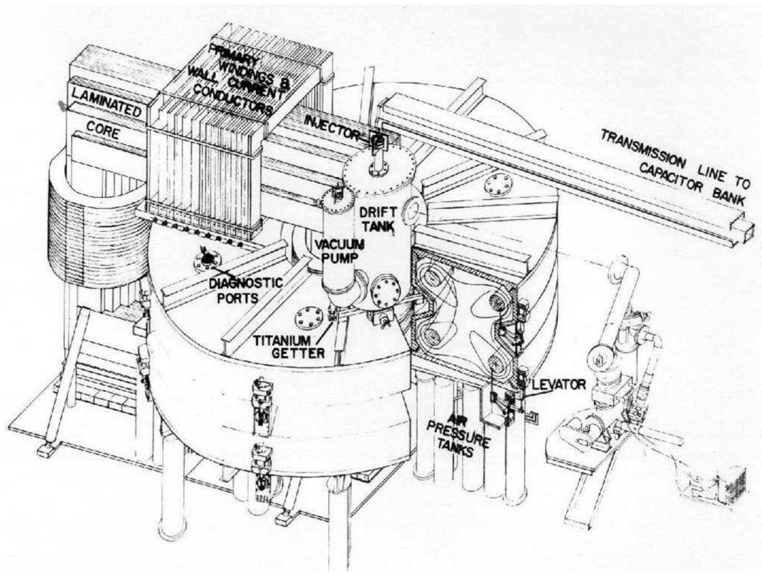
2.8 GHz and is proportional to the magnetic field strength. By comparison, a microwave oven uses a frequency of 2.45 GHz.

[3]Densities as high as $10^{17}$ particles/m$^3$ and temperatures as high as 10 million degrees Celsius were achieved using microwave sources with frequencies in the range of 700–9000 MHz and powers as large a 100 kW with a typical pulse length of 144 microseconds.

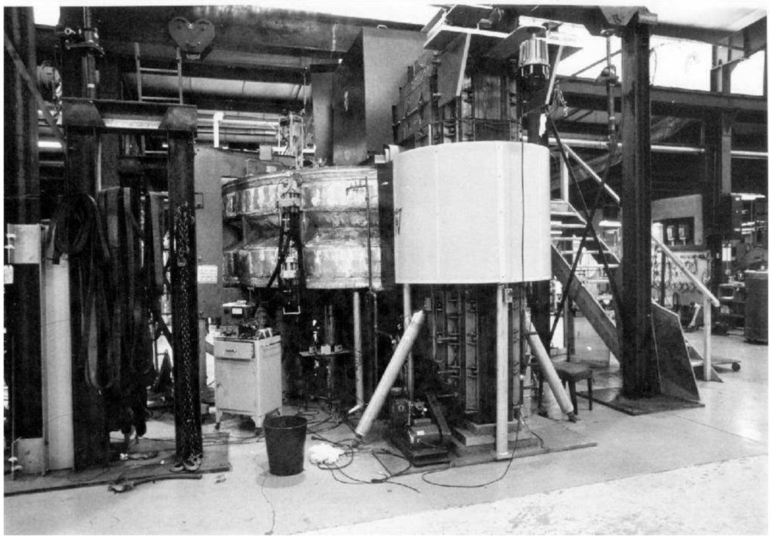
near Stoughton, WI, that had previously been the headquarters of MURA and recently purchased by the University. The Levitated Octupole was a much larger device with a 50-ton iron core and four aluminum hoops that weighed about a ton each and that were dropped and then caught during the 50-millisecond magnetic field pulse to remove the hoop supports that were thought to dominate the loss of plasma from the 'small' Toroidal Octupole.




Schematic of the Levitated Octupole device.

As if that were not enough to keep me busy, I also had a quarter-time job in the Electrical Engineering Department. Professor Leon Shohet was taking a sabbatical in France and asked me to take charge of his lab and graduate students during his absence. His main experiment was an electron cyclotron heated mirror machine[4] similar to those being studied at the Oak Ridge National Lab (ORNL), where he had previously spent a summer working, and using the same microwave technology with which I had become familiar. He had three graduate students, Ken Connor, David Greene, and Tom Casper, and a number of undergraduate student helpers. It was a great experience to

[4]In a magnetic mirror machine, the magnetic field lines leave the device out the ends, but the plasma is confined by virtue of the field being stronger at the ends than in the middle, causing the charged particles to reflect as if between two mirrors. The Van Allen belt is a plasma confined by the magnetic field lines of the Earth and mirroring between the poles, giving rise to the aurora.



Levitated Octupole at PSL in about 1971.

be completely in charge of a laboratory, to have students of my own, and to get some experience writing progress reports and proposals. I had four offices during that year, one at the Barn, one at PSL, one in Electrical Engineering, and one in the Physics Department that was damaged in the Sterling Hall bombing on August 24, 1970, during my last week as a postdoc.

I was also applying for jobs to continue my physics career. It was a good time for fresh PhDs, especially in plasma physics, and I did little more than to have Don Kerst mention to a few people that I was looking for a job. I had four job interviews: Sandia National Laboratories in Albuquerque, General Atomics in San Diego, Lawrence Livermore National Laboratory in Livermore, California, and Oak Ridge National Laboratory in Tennessee. I was not so interested in the Sandia job, which basically involved developing directed energy weapons for missile defense (subsequently called the 'Strategic Defense Initiative' or 'Star Wars'), and as a result they did not give me an offer, but the other three did. The GA position was in the group that Kerst had led a decade earlier working on toroidal multipoles under the direction of Tihiro Ohkawa. Livermore also had a toroidal multipole under the direction of Charles Hartman, but my offer from them was not to work in that group but rather to work for Rudy Bauer who was also developing directed energy weapons for defense work, and so it was of less interest to me. Understand that this was at the end of the Vietnam War, and antiwar sentiment was strong, especially on university campuses. The Oak Ridge offer was to work on an ECRH mirror machine called Elmo[5] under the direction of Ray Dandl. Oak Ridge was the premier laboratory in ECRH, and it seemed the ideal job for me to continue the research I had begun at Wisconsin.

The next phase of my career began when I arrived in Oak Ridge on September 4, 1970. Nestled in the hills of East Tennessee, ORNL was a laboratory built during World War II to enrich uranium for the Manhattan Project. Remnants of the gates and guardhouses that secured the town during the War were still in evidence. The lab was spread out over three sites in different valleys and behind security fences with active guardhouses. 'Downtown Oak Ridge' was basically a shopping mall, and it seemed that almost everyone wore the security badges that were required for workers at the lab and that had their photograph and a photographic film to monitor radiation exposure. Although my work there was not classified, I was required to have a Q clearance, which was useful because I could take a shortcut through the high security area to get to work from the parking lot, and for some reason the cafeteria and library were in the secure area. I'm not aware of ever coming into contact with any secret information, but if I had, I couldn't tell you about it here. The security fences were removed only in 2001.

The Thermonuclear Division where I worked was located in a large building that had housed a cluster of calutrons (electromagnetic separators) for uranium enrichment during the War, and there was still evidence of them in the building. In addition to Elmo, there were two other ECRH mirror devices—INTEREM, headed by Julian Dunlap, and IMP (Injection into Microwave Plasmas), headed by Norm Lazar, in which the ECRH plasmas were used as a target for the injection of energetic neutral beams, as well as a mirror device heated by strong dc electric fields, directed by Igor Alexeff, a clever inventor and a bit of a maverick. Somehow, Igor and I hit it off and remained friends long after I left the laboratory.

The Elmo device was unusual because it produced a ring of 1 MeV electrons whose current modified the magnetic field in a way that produced a minimum-$B$ configuration similar to that in the Toroidal Octupole on which

[5]People generally assumed that 'Elmo' was an aconynm for this electron cyclotron heated mirror device, but Ray Dandl explained it was just a homely name that he chose in reaction to the pompous names others were giving to their machines and because it was vaguely suggestive of St. Elmo's Fire, the luminous coronal plasma sometimes observed surrounding the mast of a ship during a thunderstorm.

I had done my thesis. Two other physicists were working on the Elmo device—Alan England and Phil Edmonds—and we became close colleagues and shared adventures spelunking and playing softball on the intramural team. Other prominent members of the group were Odell Eason, a senior microwave engineer, Carl Becker, an electrical engineer and fellow ham radio operator, three gifted and friendly technicians, Mac McGuffin, Bob Livisey, and Glenn Bryson and his cousin Norma Bryson, who was the group secretary and helped me in many ways.

The work environment was very different from the university. The technicians were members of a strong union that forbid the physicists from doing much of anything in the lab for themselves except taking and analyzing data. In addition, they took orders only from the group leader, Ray Dandl, who didn't always involve us in his plans and decisions. It was not a situation in which I could easily exploit my laboratory skills, and so I taught myself computer programming using FOCAL on the DEC PDP-8 minicomputer that had just been purchased to analyze data from the IMP device and later using FORTRAN on the laboratory-wide mainframe computer. It was done with punched cards and overnight runs that were transported by courier to the laboratory mainframe computer in the other valley.

I had developed a love/hate relationship with computers that began while I was an undergraduate at MIT. I had signed up for a computer course but soon dropped it because the programming they were teaching us made little sense to me. It was the only course I ever dropped. That led to a fear of computers that persisted throughout graduate school. Fortunately, there were a couple of undergraduates in the plasma lab at Wisconsin who did the FORTRAN computations that I needed to finish my thesis. One of these was Jeff Berryman, whose younger brother Peter, became a well-known musician and song writer in Madison, and the other was Del Marshall, who later entered graduate school, then dropped out and worked for forty years as a carpenter before returning to finish his physics PhD and becoming the head teaching assistant in my course and eventually a research collaborator. At Oak Ridge, I discovered that having a problem that one much wanted to solve and having easy interactive access to a computer were the keys to developing programming skills, which turned out not to be difficult and many years later facilitated a radical change in my research direction.

Much of my interaction was with members of the theory group, especially the group leader Gareth Guest. In addition to the impediments I was having doing experiments, I found the work environment a bit stifling. Everyone came and went at the same hour, and it felt like working in a factory with limited educational opportunities outside my immediate field. Also, there wasn't much to do in the town after work hours, although the Smoky Mountain National Park was only an hour away, and I spent many weekends climbing mountains and hiking the trails. It was also during that time that I decided to get a pilot's license and revive the ham radio hobby that had been idle for a decade.

After working there for two years, Don Kerst suggested I spend the summer of 1972 back in Madison working on the Levitated Octupole, which by then was beginning to produce data. I jumped at the chance. At the end of the summer, he suggested I stay on for the academic year, and Leon Shohet arranged a part-time visiting professor position for me in Electrical Engineering. I believe I had a 1/3-time appointment in EE and a 3/4-time appointment in Physics, which would probably not be possible today. During that year, Herman Postma, the director of the Thermonuclear Division at ORNL and who later became the director of the entire ORNL, called to say that there had been budget cuts and that he would be pleased if I decided to resign the position from which I was on leave. In essence, I was being fired. Fortunately, Don Kerst had already begun the process of getting me an assistant professor offer to replace Dale Meade, who had been on the faculty but had left to work at the Princeton Plasma Physics Lab. I also interviewed for an assistant professor position in the Nuclear Engineering Department at MIT working on their new tokamak device (ALCATOR) with Bruno Coppi, but I didn't get an offer from them because I showed little interest in ALCATOR, which was just fine because I later learned that they rarely promoted junior faculty, and besides, my heart and mind were in Wisconsin. Thus began my career as a physics professor.

# Chapter 8

# The Persistent Pilot

> I confess that in 1901, I said to my brother Orville that man would not fly for fifty years. —Wilbur Wright, 1908

When one has been in school for twenty-two years, it's a bit of a shock to suddenly be out in the real world as I was when I began my job at Oak Ridge. I missed the intellectual life of the university, and I found myself for the first time in many years with spare time on my hands. I was ripe for another mental challenge. Thus when in July of 1971 I saw the plane pulling a banner over the city of Oak Ridge offering flying lessons, it did not take me long to get to the nearby Powell, Tennessee airport to fulfill a latent dream and begin a hobby that would entertain me for the next thirty-six years.

Until it was sold for development in 2008, Powell was a small private airport on the outskirts of Knoxville owned and operated by Norman Mayes and his wife. It had a 2600-foot asphalt runway with Interstate 75 at one end of the runway and tall power lines at the other end. I later learned that if one could safely take off and land there, it could be done almost anywhere. Norman had several small Cessnas that were used for training and rental. It cost $11 an hour to rent a Cessna 150 (including fuel), and I think about $5 an hour for an instructor, which was easily accommodated on my $16,000 per year salary at the laboratory. My flight instructor was Ralph Holder, a sixtyish insurance salesman who had only learned to fly a few years before. We got along well, and he was impressed with my academic credentials and quick learning.

After our sixth dual flight over a span of three weeks and a mere 6.3 hours under my belt, he declared that I was ready to solo. Three days later, I went to the airport a bit apprehensive, and he accompanied me for a couple of landings, which were among my worst, and he said that I would not be soloing that day, to my considerable disappointment. Two days later, I returned to the airport determined to do well, and within two hours I had done several dual landings and several solo. They spared me from having my shirt tail cut off as was once the custom,[1] but Ralph took a photo of me by the plane that I still treasure.


After my first solo flight on August 22, 1971 in a Cessna 150.

Learning to control the plane and land and take off is only a small step toward becoming a private pilot, for which one had to accumulate forty hours including a solo cross-country flight of at least a hundred miles, night flights, landing at an airport with a control tower, and flying solely on instruments. I needed to have a medical exam, pass a written test with a score of at least 70%, and finally fly with an FAA examiner. That all went smoothly, and my written score was 95% I think. I forget what question I missed.

On November 11, 1971 with a total of 40.7 hours, I departed on the twenty-minute flight to Morristown, Tennessee to take my flight test with Evelyn Bryan Johnson, the designated FAA examiner in the area. She was a sixty-two-year-old woman who had been flying for twenty-seven years. She was friendly but thorough, and I recall that we simulated a radio failure and

[1] In the early days of aviation, the instructor sat behind the student pilot in the plane and would tug on his shirt tail to get his attention. Cutting off the shirt tail was thus an expression by the instructor that the pilot was competent to fly alone.

she asked me to plot a course to an alternate airport using only the map, which was easy on that crystal clear day. What I didn't know at the time was that she was early in her career in aviation and that she would continue giving flying lessons and exams for another thirty-four years until she eventually lost her medical certification due to glaucoma. She was listed in the Guinness Book of World Records as having the most flight hours (57,635.4) of any living pilot. She won numerous aviation awards and managed the Morristown Airport until her death on May 10, 2012 at age 102. It's an honor to have her neatly written and legible signature in my logbook.

Evelyn Bryan Johnson, the FAA examiner who gave me a flight test for the private pilot's license on November 11, 1971 and who later held the world record for the most flight hours of any living pilot.

After giving rides to a few friends, I took my first trip by plane, a three-hour flight to Memphis for Christmas where my parents and other relatives lived. I was accompanied by Ralph, my small fox terrier, named before I met my flight instructor with the same name. It was just a whimsical name for a dog, but I later rationalized that it was one of the few names he could pronounce. Ralph was not adventurous, but he was comfortable riding in the car and must have thought the airplane was just a noisy automobile until we got up to about a thousand feet, at which time he glanced out the window and thereafter insisted on sitting in my lap shivering for the rest of the trip. I had to tie his leash to the opposite door handle to keep him from interfering with my ability to control the plane.

The first exciting adventure came when showing off my flying skills to my father. I was flying him over some of the lakes in northwest Mississippi where he frequently hunted ducks with my brother. About half an hour from the airport, a loud grinding noise suddenly appeared in the cockpit. I had no idea what it was, but the engine was still running, and the plane was flying just fine. I called Memphis Approach Control and reported a rough engine, and they gave us vectors to Twinkletown, a small grass strip on the outskirts of Memphis where we landed. A seasoned pilot there had a look and correctly diagnosed it as a bad tachometer cable, which we got fixed a few days later. I think it was also on that trip that I ran the battery down by leaving the electrical master power switch on overnight. A helpful pilot got the engine started by hand-cranking the prop, and we recharged the battery while flying. The first problem was not my fault, but the second clearly was.

The following summer I moved back to Madison and got checked out to fly the airplanes at Four Lakes Aviation (now Wisconsin Aviation). After I realized I would be there for at least a year, I began taking instrument lessons so that I could depend on the airplane for transportation in almost any weather conditions. The instrument rating required two hundred hours total flight, including forty hours of actual or simulated instrument flight, as well as a difficult written exam and a flight test by an FAA examiner. It took me another ten months to satisfy the requirements.

My first instrument instructor was Alan Bliesner, a young hot-shot who flew F-102 jets for the National Guard on the weekends. We flew in a Piper Arrow with retractable gear and a variable speed prop. Midway through my instrument training, he was hired by American Airlines, and I would occasionally see him in the O'Hare airport during my many commutes to St. Louis. When I mentioned to the owners of Four Lakes Aviation that I was anxious to finish my instrument training so that I could take trips in bad weather, they replied, 'Oh, we don't rent our planes for solo instrument flight.' I used that as an excuse to move across the airport to Frickleton Aviation, where there was no such policy, and to a colorful instructor named Jake Miller.

Jake was a pilot's pilot. He had his own airport in Stoughton, WI from which he gave glider instruction. He also taught aerobatics and was well known for his antics such as flipping the plane upside down while a beginning student was talking to the tower on final approach, which is illegal but seemed to be tolerated by his friends in the tower. He also preferred the Cessnas that I had mostly flown, and he had a Cessna 150 with an oversized engine and propeller that he used to tow banners over the football stadium on game days. His style nicely complimented mine, and more than once he told me not to worry about all the numbers and just fly the plane so it felt right. One of my most cherished flying compliments came when the Madison tower mistook me for Jake since our deep bass voices sound rather similar on the radio.

One memorable day, he was checking me out to fly his special Cessna 150 so that I could rent it to fly to the East Coast. It was a windy day, and he wanted to show me a 'maximum performance takeoff.' He cautioned me not to touch the controls, ran the oversized engine up to full power, and then released the brakes. Seconds later we were airborne climbing at a steep angle into the stiff headwind and drifting backwards as we gained altitude. The tower, noticing this peculiar maneuver, radioed 'Jake, what are your intentions.' (The tower never calls anyone else by name.) I well recall Jake saying 'we'll just back up and land on the same runway.' Meanwhile they were landing planes under us, cautioning them about the 'Cessna hovering over the end of the runway' while we were experimenting with how to control an airplane flying backwards. Of course, relative to the wind, we were going forward, and so the control was quite ordinary, but it was a strange sensation to look out the window. When the time came, he put the nose down and landed right where we had started the flight fifteen minutes earlier without ever making a turn. The next day, other pilots were trying the same stunt as word got around, but none succeeded because it needed the small, powerful airplane and stiff headwind.

It was only two weeks after that adventure that I had my first and only experience damaging an airplane. I had taken my girlfriend at the time in Jake's beloved plane to Memphis and Knoxville, and then we landed at the College Park, MD airport, where I was instructed by the tower to taxi off the runway onto the grass. Unfortunately, there were potholes, and the oversized propeller only cleared the ground by about six inches. Sure enough, I hit a bump, and the propeller struck the ground, bending its tip with a loud noise and sending mud all over the windshield. Two days and $300 later, we were off to finish the trip to Teterboro, NJ and Cleveland, OH before returning to Madison. Only decades later did I learn of the legal requirement to disassemble and inspect the engine following any such propeller strike, which would have been expensive and time-consuming.

About the time that trip was over, I had accumulated the 200 hours needed for the instrument rating, and I scheduled my instrument flight test on July 22, 1973 with the FAA examiner, Clyde Frickleton, Sr., who owned the company from which I was renting planes and taking instrument lessons. He was a gruff, no nonsense type. Things were going reasonably well until he asked me to do an ADF approach to runway 36 at Madison, which I had done many times. It is perhaps the most difficult instrument approach, and it is rarely done anymore except in practice. I thought I was doing ok, but apparently he didn't, and he started yelling at me. He told me to take the hood off and land the plane, whereupon he stomped away without saying anything. I assumed I had failed the test. Once I had the plane tied down and sheepishly entered the terminal building, he handed me my logbook with the notation 'Instrument Approved,' and said something like 'keep learning.'

Armed with an instrument rating, good instruction, and an important dose of humility, I began a decade of taking trips whenever I could find an excuse to fly somewhere. I made numerous personal trips including to Memphis, Chicago, Milwaukee, Knoxville, and the Bahamas. Each fall I would load the plane with my students and fly to the Division of Plasma Physics meeting of the American Physical Society. Those meetings were held in Philadelphia, Albuquerque, Tampa Bay, Atlanta, Colorado Springs, and New Orleans. Eventually, the novelty wore off, and the students preferred the comfort and speed of the airlines. Also the paperwork required by the University to get insurance and reimbursement for those trips was taking a lot of time. Furthermore, the University required that I fly fifty hours each year, and so I bought an ATC 610J flight simulator for $4000 to help meet that requirement, but it got boring after 230 hours of simulated flight, and so I finally quit flying for business, and the flight simulator lapsed into a state of disrepair where it still stands.

Most of those trips were uneventful, but a few stand out. The trip to the Bahamas was in connection with a sailing adventure with Don Kerst who kept his boat at Treasure Cay and wanted me to sail it back to Vero Beach, Florida with him, which I did and then took a commercial flight back to the Bahamas to retrieve the airplane. That trip was over a significant amount of ocean in a single-engine Cessna 172 without a life raft. The customs agent at Fort Lauderdale was duly suspicious of this young guy flying from the Bahamas alone, and he checked the plane very carefully for drugs. In retrospect, I was lucky because it was a rented plane, and it might well have been used for illegal activity in the past.

On another trip, after departing Philadelphia with a load of students, I was returning to Madison with a strong headwind. Somewhere over central Pennsylvania, New York Center called on the radio asking us to report our ground speed. When I said '70 knots' he responded 'that's why I don't see you; my radar only responds to moving targets.' Eventually, we got back safely but not before picking up some ice on the wings while crossing Lake Michigan in the dark. Some pilots avoid flying over Lake Michigan in a single-engine plane, especially at night in the winter, but I was rather fearless. I always reasoned that I could glide for ten miles or so and that there were always many boats on the Lake that could rescue us if the engine failed provided I landed near one.

The instrument rating is supposed to ensure flying in almost any weather, but the flight to Albuquerque for an APS meeting with a group of students was cut short when thunderstorms started to build up over the Rocky Mountains. Flying at night, we were within a few hundred miles of Albuquerque, but the weather was bad and the controller kept vectoring us around the worst of the storms. Finally, he said he had lost us on his radar and we were getting close to some tall mountains in Colorado. At just about that time, I spotted an airport beneath us through a break in the clouds. We landed and spent the night at Clayton, New Mexico. When we landed, the fellow at the airport tossed me the keys to a car they kept for such purposes, and said to return it tomorrow. I was apologetic to the students for getting them to the meeting a few hours late the next morning, only to discover that the commercial flights to ABQ had been canceled that night too, and so everyone was late.

Most of the planes I flew were small, single-engine, four-seat Cessna 152s and 172s, but the trip to Tampa Bay was in a Cessna 206, which seated six. At the other end of the spectrum, I let Jake Miller give me a glider lesson, but I didn't see much use for that since the flight was short and near the airport. I could get much the same effect by just cutting the power in the airplanes that I flew. I also had an occasion to pilot a Stearman, which is a World War I biplane with an open cockpit that was owned by John Mullen who worked for McDonnell Douglas where I spent one day a week consulting for three years in the mid 1970's. That was another adventure where one time was sufficient for my taste.

Over the years I often thought about owning an airplane, but I just wasn't flying enough for that to make economic sense. There are a lot of fixed costs involved with airplane ownership—insurance, inspections, maintenance, and hanger fees—in addition to the considerable time that it would consume. Furthermore, one wants a different airplane for flying around Madison on a pretty day with a single passenger and for making a long cross-country instrument flight in a plane loaded with people and baggage. It was far cheaper and more convenient to rent an airplane optimized for the particular mission. Most people are surprised to learn that a small airplane can be rented at a cost per mile that is comparable to renting a car, and with three passengers I can usually beat the cost of a commercial flight. Planes are rented by the hours that the engine runs with no charge for the time it sits idle on the ground, although there are sometimes requirements for the minimum number of hours flown per day. The plane flies much more slowly than commercial jets, but that is often offset by the flexibility in scheduling and flying direct to the most convenient airport.

Once I was no longer being reimbursed for my travels, and with the increasing cost of flying, I took fewer long trips and did most of my flying locally around the Madison airport. It was then hard to keep current on instruments since that required six hours of instrument flying in the previous six months or a check ride with an instrument instructor. To be current for carrying passengers, one has to have logged three take offs and landings in the previous ninety days, and to be current for night flight, those T&Ls must have been at night. For many years, I would go flying after dark every three months, which meant after about 9:30 pm during the summer.

On one occasion, I was doing T&Ls about 11 pm at the MSN airport, and the tower radioed 'we're going home for the evening; turn off the runway lights when you're done,' which requires five clicks of the microphone. Rarely have I felt so important as to have full control of the Madison airport. On another occasion, I watched the Fourth of July fireworks from above, which is much less spectacular than seeing them silhouetted against the dark sky.

I made many day trips to Meigs Field, the famous lakefront airport in Chicago. They had a landing fee, but it was only $7 per day, which was cheaper than I could park my car in downtown Chicago, and a well-dressed driver in a limousine would usually meet us to tie down the airplane and chauffeur us to the airport terminal. The airport was within an easy walk from the Adler Planetarium, the Shedd Aquarium, and the Field Museum of Natural History, as well as the downtown shopping district. Departing just after sunset was a memorable experience with the lights of the city glistening along the lakeshore. The Meigs airport often closed at unexpected times, and

I once had to climb across the fence to get to the airplane and depart from the deserted airport. Cross winds were often a problem in the Windy City, and I once flew there from Madison, made about three approaches to the runway, and had to return to Madison without landing because of the winds. On another occasion, the weather turned bad, and I had to land at nearby Midway. It was a disappointment when Mayor Richard Daley demolished Meigs Field over strong protests by ordering bulldozers to destroy the runway in the middle of the night on March 31, 2003, ostensibly for safety reasons in the aftermath of 9/11, without giving the required thirty-day notice to the FAA or to the owners of the sixteen planes that were left stranded at the airport.

As I got older, it was harder to find people who wanted to fly with me, and I don't like to fly alone. The novelty had long since worn off. The burden of having to watch the calendar as the ninety-day limit approached and getting the required medical and flight review every two years was making the hobby more of a nuisance than a pleasure. It was becoming expensive, and the regulations were becoming increasingly complicated and onerous. Finally, when my doctor Norman Jensen told me that he could no longer give aviation medicals because he was not doing enough of them, I decided that after thirty-six years and 626.3 hours of flight, it was time to give it up, and my last flight was on August 26, 2007.

I do miss it a bit, but not enough to do all that would be required to fly again. It's a hobby suited to the wealthy and seriously addicted, and not something that can be safely done on rare occasions, which is all I care to do at this stage in life. I can only recommend it to others and look for a chance to fly as someone's enthusiastic copilot.


Preflighting N91HL before my last flight on August 26, 2007.

# Chapter 9

# The Proud Professor

> America believes in education: the average professor earns more money in a year than a professional athlete earns in a whole week. —Evan Esar

> Education is not filling a pail, but lighting a fire. —William Butler Yeats

Being a university professor was not one of my goals, but it is probably the best and most prestigious job that one with my interests and training could have. I did not especially want to teach, and faculty positions at research universities like Wisconsin are highly prized and difficult to get. Given that I was only an average student with mediocre grades and modest intelligence, it had seemed an unobtainable goal. Yet there I was, a new assistant professor at the very university that had admitted me to graduate school on probation and denied me a teaching assistantship. I can only thank good luck, those teenage years spent tinkering with radios in the basement, hard work in the laboratory, and especially the good fortune of having a mentor in Don Kerst who believed in me and expected much of me.

New faculty in our department are usually not expected to teach in their first year, but rather to concentrate on starting a research program. My research had been underway for nearly a decade, and I felt that I wasn't a real professor until the second year when I was asked to teach the electronics course that was aimed at physics majors and engineers in fields other than electrical engineering. Don Kerst was assigned to help me in the laboratory that accompanied the course and probably to keep an eye on me in case I faltered. I had little teaching experience, but I knew that I could give nice scientific presentations, and they could have hardly chosen a better course for me to teach. It turned out that I had a knack for teaching, which was an unexpected but pleasant surprise.

Actually, I had co-taught a course for one semester two years before as part of my visiting appointment in Electrical Engineering. Since I had a PhD in physics, they asked me to help teach the undergraduate course in electromagnetism along with Ron Vernon, a young assistant professor who had taught it several times previously. I don't recall much about that experience except that the course was divided into two sections, and I taught the unpopular and lightly attended section that met at 7:45 am. It must have been a reasonably successful experience, although I can remember Ron once gently suggesting that I modify one of my exam questions so that it did not violate Maxwell's equations. It was ironic that I taught physics in the Electrical Engineering Department and electronics in the Physics Department.

During my first decade on the faculty, I taught the electronics course many times and wrote a textbook for the course that is still used by my colleagues thirty years later.[1] I also taught modern physics and the introductory plasma course. On one occasion, I was scheduled to teach the algebra-based general physics course, our largest and most unpopular course, but Bill Kraushaar, the department chairman, decided it was too big a job for me. That disappointed me, and I determined to prove that I was up to the task, which I did a few years later when I began regularly teaching the introductory courses with good student evaluations all the way until my retirement. I attribute this partly to the fact that I was never a great student, and so I had to explain things in simple terms that even I could understand. Apparently one of the best ways to get me to do something is to tell me that it's too hard for me. My teaching was eventually recognized in 1997 when I was awarded the campus-wide Van Hise Outreach Award for Excellence in Teaching, which included a $5000 supplement to my salary that year. My colleagues considered me an excellent teacher, although I was never nominated for the Teaching Academy, which I found rather curious and a bit disappointing.

It still seems odd that one typically begins a career as a university professor without ever having any formal instruction in how to teach, nor much oversight even when things are not going well. The only advice I got about teaching was from Connie Blanchard, who had admitted me to graduate school a decade earlier, when he said 'the quality of your teaching is directly

[1] J. C. Sprott, *Introduction to Modern Electronics*, John Wiley & Sons, New York, 1981.


Me giving an undergraduate general physics lecture in 1997.

proportional to the time you spend preparing, without limit.' He was an excellent teacher and a master of short, pithy quotes, and the words stuck with me and inspired me to prepare carefully in the early years. As time went on, I got lazy and routinely walked into lecture to a room filled with 300 students using only my ragged notes from previous years, not looked at for a year. My decreasing efforts were offset by my increasing experience, and I continued to do a respectable job especially since I enjoyed doing demonstrations, and those were popular with the students. As a result of research on physics education, many new teaching methods were being developed, but I kept doing things as I and those before me always had. One reason I eventually retired was because of the excessive repetition and so that others could implement the modern methods.

In thirty-five years of teaching, I did develop a philosophy of teaching, especially for the lower-level courses that I mostly taught toward the end of my career. A common problem I saw with many teachers is that they failed to motivate the material, talked over the head of the students, and generally gave boring lectures, devoid of context. Some of my colleagues taught undergraduates the same way they would give a research seminar using PowerPoint slides. This always struck me as inappropriate, although I tried it a few times. I felt comfortable and well organized, but I think the students had a tendency to fall asleep, especially if the lights are dimmed. Another colleague, whom I greatly admired, had a chatty lecture style, telling stories and jokes. He was popular with the students, but his style was quite different from mine. When we once co-taught a course, I feared that I would be unpopular by comparison, but our student evaluations were similar with an equal number strongly preferring our respective styles.

I was strongly influenced by educational research that showed that lecturing in which the professor talked and the students listened passively ('the sage on the stage') is the worst possible way to teach, and the little bit that students learned that way shows little correlation with the popularity of the teacher or the quality of the presentation. The conventional wisdom is that the lectures need to be interactive ('the guide on the side'), but I was never good at that. Thus I concluded that my primary goal in the lecture would not be to teach but rather to motivate and to demonstrate. I would try to convince the students that the material was interesting and useful, and I would show them things that they were not likely to have seen before and that they would remember for years to come. I feel that I was only partly successful, but I finished my teaching career with a reputation of being a good teacher, whether deserved or not.

Our university has a strong tradition of faculty governance, and most decisions at the department level are made by committees and voted on in faculty meetings. All faculty are expected to select a few committees on which to serve. This was not something I enjoyed or was good at. Early in my career, I considered it an honor, and I served on a variety of committees, but as time went on, I gravitated to a few committees that involved issues I cared about such as introductory courses, lecture room, and outreach, but I was not a proactive member of the committees, and I especially dreaded those times I was asked to chair a committee. I could probably count on one hand the number of times I spoke up in the biweekly faculty meetings that I attended religiously for thirty-five years, and on the other hand the number of times I made a report on behalf of a committee. As a result, I was never seriously considered as a candidate for department chair, which suited me just fine. I served on a couple of college and university committees and was a faculty senator for eleven years since that only required attending a meeting chaired by the Chancellor once a month and voting on a succession of mostly noncontroversial issues. Some people consider being a professor as a stepping stone to a position as Dean or other university administrator, but that had absolutely no appeal to me.

When one is hired as an assistant professor, the tenure clock begins running. At the end of seven years, the position ends (one is 'fired') unless promoted to associate professor, which at Wisconsin includes lifetime tenure. The concept of tenure was originally intended to provide assurance that one cannot be fired for holding views and teaching things that are politically unpopular or offensive, and it is a guarantee of academic freedom. One can only be fired for gross incompetence or failure to meet one's responsibilities such as teaching an assigned class. With Don Kerst in my corner, I was blissfully unaware of and unconcerned with the possibility of not being promoted, and I was granted tenure after five years as an assistant professor, which is fairly typical. After later watching the difficult time other good assistant professors had getting promoted or being terminated, I realized how lucky I was to have the support of Don Kerst.

My research was an evolution of the work I had done as a graduate student. I continued with studies of ECRH and ICRH on the octupole devices, which had fallen out of favor with the fusion community when the tokamak, a Russian invention that is still the leading candidate for a fusion reactor, came along shortly after my graduation. When I began work at Oak Ridge, the laboratory was in the midst of constructing its own tokamak called Ormak, under the direction of the seasoned fusion scientist George Kelley and jointly designed by Kelley and his younger colleagues John Clarke and Mike Roberts who had learned and exploited many of the techniques developed by Kerst at Wisconsin for producing highly precise magnetic fields.

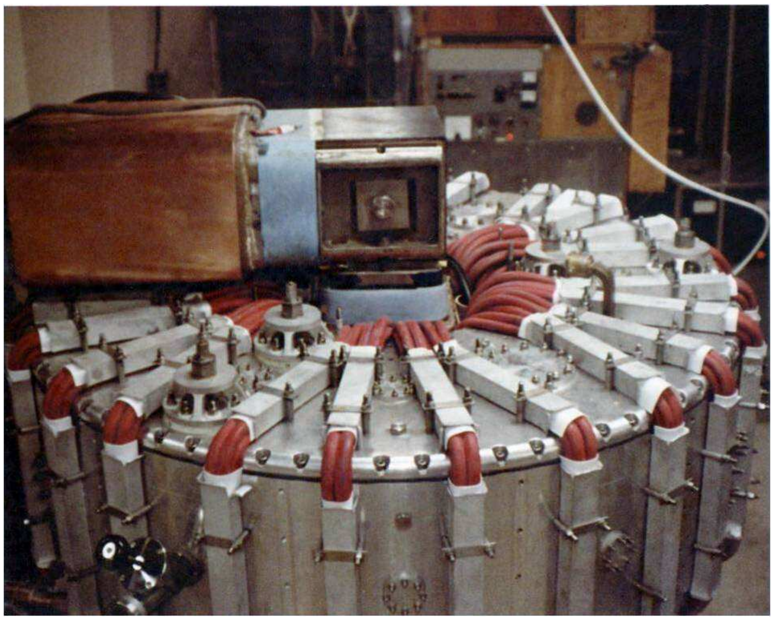
The Toroidal Octupole on which I had done my thesis had fallen into a state of disrepair with most of the effort shifting to the Levitated Octupole. I mounted an effort with the help of Tom Lovell, a talented young technician who had assisted me when I was a graduate student, to bring it back to life and to operate it in a hybrid mode that had features of both the octupole and the tokamak, and that we called the Tokapole. Basically, this required increasing the magnetic field strength and driving a large inductive current in the plasma to heat it. It worked, but not very well because the machine had not been designed for that purpose, and it was showing its age.

A few years later, Lovell and I engineered a new device, about the same size as the Toroidal Octupole but with many improvements, which we called Tokapole II. By then two additional faculty had joined the group. Stewart Prager was a bright new assistant professor from General Atomics, and Dick Dexter was a solid state physicist and spectroscopist in our department, whom my graduate student Rich Groeber had lured into helping us diagnose the Tokapole II plasma. The three of us supervised the research on that device for the next decade and also worked on the Levitated Octupole, which had a brief comeback as people realized that it might be a candidate for a fusion reactor using 'advanced fuels,' particularly the isotope Boron-11, which reacts with protons to produce only helium with no neutrons and hence no wall damage and no radioactive waste. It was a fortuitous situation because the multipole had been rejected as a fusion reactor concept because no one could see how to protect the hoops from neutron damage using the conventional fusion fuels of deuterium and tritium. The interest soon waned when calculations showed that there would be excessive energy loss due to microwave synchrotron radiation from the required billion-degree plasma.

Dick Dexter, Stewart Prager, and me, beside Tokapole II shortly after its construction was complete.

During that time, I followed with interest the development of the ECRH plasmas at Oak Ridge and went back a few times to consult with them. They had constructed a device called EBT (Elmo Bumpy Torus), which was a series of mirror machines like Elmo strung end-to-end around in a circle. It was making interesting plasmas, and a committee had recommended building a larger second-generation device as a fusion proof of concept, for which the Department of Energy (DoE)[2] put out a request for proposals. McDonnell

[2]DoE was established in 1977 as a combination of the Federal Energy Administration



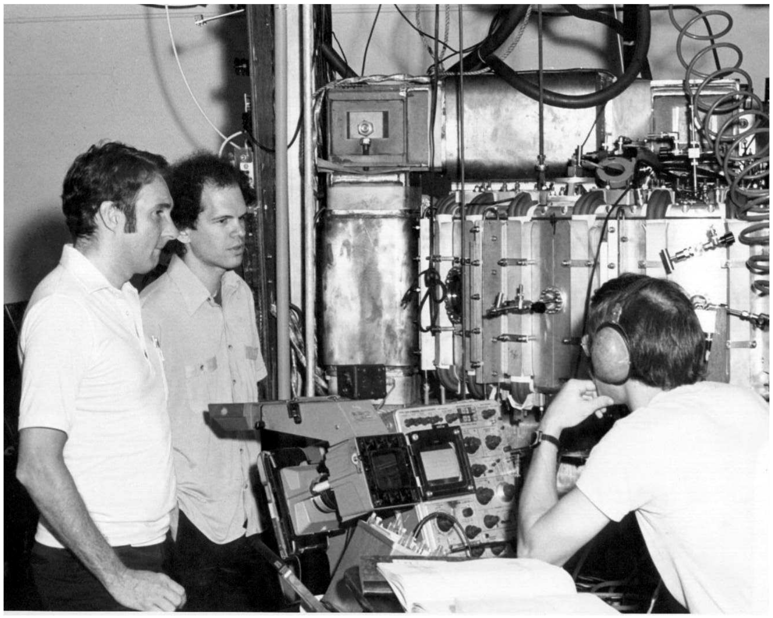
Closeup view of Tokapole II.

Douglas in St. Louis formed a team to study the issue and prepare a proposal, and they hired me as a consultant.

For three years I spent one day a week in St. Louis, usually taking a commercial flight from Madison early on Wednesday morning and returning about 10 pm the same day. A highlight of that experience was flying to DoE headquarters in Washington on their company Learjet, which was high adventure for a relatively new private pilot like me. Much of the time on airplanes and in airports was spent writing the electronics textbook for the course I still occasionally taught, and I bought a lifetime membership in American Airlines' Admiral's Club so I would have a good place to work in O'Hare and at St. Louis while waiting for flights.

At one point, McDonnell Douglas tried to hire me to head their fusion program, offering nearly twice my university salary, but I was happy at the university, and I helped them locate and hire several other plasma physicists. I also taught a course on plasma physics in St. Louis to educate some

(FEA) and the Energy Research and Development Administration (ERDA), which in turn was formed when the Nuclear Regulatory Commission (NRC) was split in 1975 from the Atomic Energy Commission (AEC), an organization established after World War II by Congress to foster and control the peacetime development of atomic science and technology.



Me with Stewart Prager and my graduate student Doug Witherspoon taking data on Tokapole II.

of their staff. They ultimately won the competition against three other companies and promptly dismissed me as a consultant. I was relieved that I had stayed at the university when the funds for the project were never released and interest in the bumpy torus as a fusion concept evaporated. The outside offer did accelerate my promotion to full professor just before salary increases were routinely coupled to promotions. I had a number of other more limited consulting jobs over the following years including with TRW in Redondo Beach, California on advanced fuel multipoles and ICRH, Argonne National Laboratory in Chicago on tokamaks, and Honeywell in Minneapolis on plasma diagnostics, as well as with a couple of book publishers and the Chicago Museum of Science and Industry.

I had become accustomed to having a break from my university duties mid-week and began working at home one day a week, a habit that continued until my retirement and something I never could have done as an employee of McDonnell Douglas or almost anywhere else. Since retiring, I usually go to campus every day when I am in town, although not always very early, and a colleague once said to me ‘it’s Thursday; what are you doing here?’ to which I quickly replied ‘I don’t have anything to stay away from anymore.’

The point is that I had previously worked at home to get away from the interruptions and meetings, which largely abated once I retired, and I can now decide on most days when I get up whether I want to go to campus that day. I do try to schedule my meetings with students and others on Tuesdays since I nearly always attend the Chaos and Complex Systems Seminar at Tuesday noon, since I was its co-founder.

In 1977 an event occurred whose significance would only be apparent a decade later. I purchased my first personal computer, a Radio Shack TRS-80 with 16 kB of memory (about two million times less than the 3 GB laptop computer on which I'm typing this). It had no hard drive, nor even even a floppy drive, but stored its programs on an audio cassette tape and booted to a BASIC prompt. It was meant to be only a toy, but I was soon doing serious calculations with it, and I bought a second one and connected it to our Tokapole II device to collect data and monitor its operation. Playing with the computer became my hobby, much as ham radio had been earlier, and I became obsessed with pushing it to its limits often writing programs in assembly language to optimize performance. I wrote my own word processor, spell checker, finance program, flight simulator, Morse code translator, and many other programs before such software was commercially available. I sold some of those programs on cassette tape out of my apartment and had the makings of a software business had I devoted full time to it. I also began a computer dating service and had several hundred clients before others came along with more extensive clientele and fancier programs and marketing.

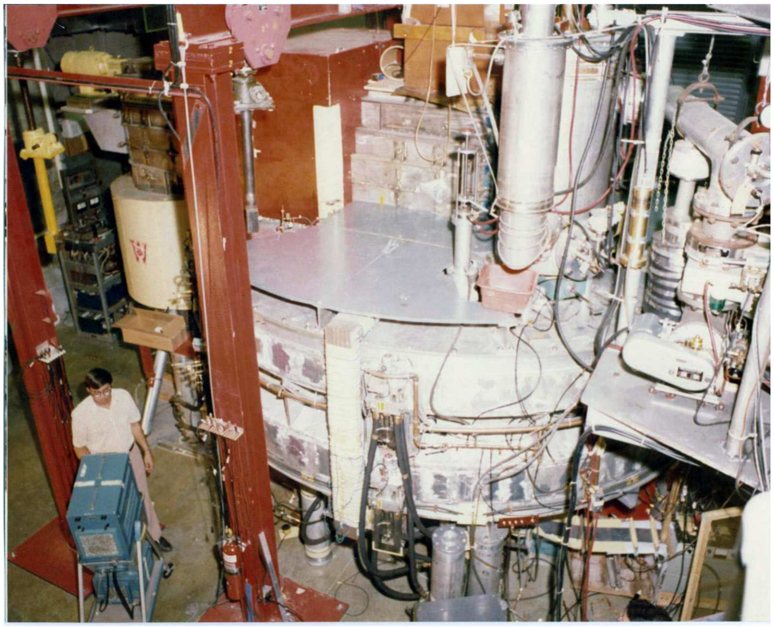
As personal computers evolved over the next decade, so did my skills, and I owned a succession of machines, buying a new one every year or two. I interfaced one of those computers to my ham radio, programmed it to send and receive Morse code and make contacts automatically, and wrote an article about that for *QST*, the premier amateur radio journal. I wrote several other articles for computer magazines and a series of animated physics demonstrations that were later marketed by Physics Academic Software, on whose editorial board served I served until it was disbanded in 2011. I also translated all the programs in the book *Numerical Recipes* into BASIC and published the code in a book with Cambridge University Press. This was all before it was fully acceptable for a professor to own or use a personal computer, which was still not considered a serious research tool.

A turning point came in 1980 when Don Kerst retired. He had been the undisputed leader of the plasma physics group and the principal investigator (PI) of our federal research grants. He had also shielded me and others from

My first personal computer, a Radio Shack TRS-80, in 1977.

the administrative tasks of running a large research group. By default, I was the logical one to take over those duties, which I did for the next five years. Aside from some prestige and honor, it was not a job I relished or did particularly well. Much of my time was spent worrying about budgets, hiring and firing, and writing proposals and progress reports. Furthermore, a PI is expected to be a bit of a salesman and advocate for the research. I was inherently shy and did not excel at those tasks and did not interact well with the reviewers and the contract monitors at DoE. I missed the years as a graduate student when I spent full time thinking about physics, and I was more comfortable interacting with my computer than with humans. Kerst began spending half the year at his second home in Vero Beach, Florida where he had a nice sailboat, and he eventually sold his house in Madison and moved permanently to Florida, leaving me alone with the project administration, although he never lost interest in what we were doing and would frequently call to inquire about our progress.

Meanwhile, Stewart Prager was taking increasing responsibilities and decided that our group should propose to build a reversed field pinch device that had shown some promise as a competitor to the tokamak as a fusion reactor and, like the multipole, did not require the large magnetic fields of a tokamak and so could be built inexpensively using much of the equipment from the Levitated Octupole. He did all the things that I should have done to gain the support of the scientific community and to sell the idea to DoE, who

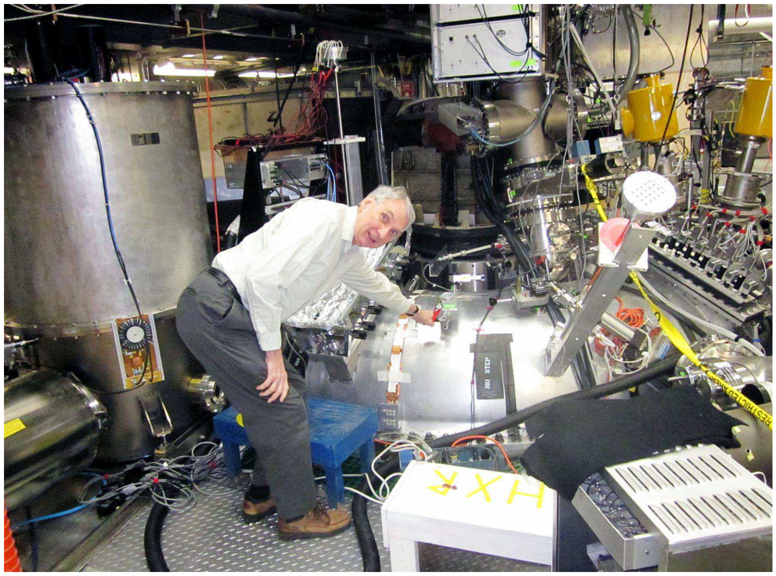


John Laufenberg working next to the Levitated Octupole.

eventually funded its design and construction, but only if we shut down both the Levitated Octupole and Tokapole II. The design and construction was overseen by Stewart, Dick Dexter, Tom Lovell, and myself, with Don Kerst acting as a helpful consultant. We called the device the Madison Symmetric Torus (MST), and it was without doubt a beautiful machine.

It was becoming increasingly clear that this would be Stewart's machine, and given my dislike for administration, I offered for him to be PI, which he eagerly accepted in 1985 and continued until he left to become director of the Princeton Plasma Physics Lab in 2009, whereupon the duties were handed over to my former graduate student, John Sarff, who had been a scientist with the group and was hastily promoted to professor. I worked on MST for about a year after its construction was complete and was responsible for producing the first field reversed plasmas and optimizing them before my interests changed in a different and completely unexpected direction in 1989.

I cannot conclude a discussion of my life as a professor without acknowledging the students that I supervised in their own quests for academic credentials. It is no secret that a professor's productivity and success are largely dictated by the quality of his or her students. Over my career, I supervised the PhD theses of eighteen graduate students and had several postdocs. For



The MST device, which was the culmination of my work in plasma physics.

the second half of my career, after I no longer had the comfortable funding afforded by our plasma grants, I worked with a similar number of bright undergraduates. I will not attempt to mention them all by name, but the success that many of them have had in their careers, the awards they have won, and the impact they have had on the field are among my proudest achievements. I did not always do a good job in mentoring students, and many of their accomplishments were probably in spite of me rather than because of me, but I look on their success with the same pride that a father has in his accomplished children.

# Chapter 10

# The Wonders of Physics

> In the matter of physics, the first lessons should contain nothing but what is experimental and interesting to see. A pretty experiment is in itself often more valuable than twenty formulae extracted from our minds. —Albert Einstein

Late one afternoon in December of 1983, the phone rang. It was Ilona Loser, a woman friend who more than anyone could pry me away from my computers and get me to do interesting things. 'Do you want to go to a chemistry lecture?' She had just watched on television an interview with Bassam Shakhashiri, a professor in the Chemistry Department, who was giving a public lecture that evening. I had heard of the lectures that he had given just before Christmas for the past dozen years but had never attended one and was curious what all the excitement was about. How could a chemistry lecture be a major public event worthy of an interview on the television news?

We arrived at the lecture room in the Chemistry building filled with bright lights and television cameras and packed with an audience ranging from young children to elderly adults. There was excitement in the air. The presentation itself was rather ordinary—a succession of chemistry demonstrations like ones I had seen as an undergraduate, but presented rapidly with a minimum of explanation and a bit of drama. What amazed me was the reaction of the audience. Children would shout out answers to questions and excitedly wave their hands to volunteer their help with the demonstrations, and everyone would applaud at every explosion or change in color of the chemicals. There were smiles and laughter like one would expect at a circus.


Bassam Shakhashiri giving his annual Christmas lecture in December of 2006.

It happened that a few months before, I had begun teaching a general physics course for the first time. It was a calculus-level course aimed at students trying to get admitted into engineering, and the Engineering College used it to weed out inferior students. Thus it was not a popular course, and the students were mainly concerned about grades. I had been assigned to co-teach with Jim Lawler, a bright young assistant professor who had been a student in my plasma physics course a few years before while he was a graduate student. He had taught the course the previous semester and was repeating it to improve his teaching. The format was two lectures a week, and we decided to alternate lectures, with him introducing each topic and developing the theory, and then I would give the second lecture reviewing what he had taught and showing demonstrations. Not surprisingly, the students found my lectures more understandable and enjoyable, and Jim vowed never again to teach a general physics course after the semester was over, and to my knowledge he never did. While I was doing a respectable job teaching the course, the students were extremely passive and showed little enthusiasm for even the best of the demonstrations. It was a stark contrast to the reaction that Bassam was getting to his demonstrations even though it seemed to me that the physics demonstrations were much more interesting and exciting than the chemical ones. In fact his most popular demonstrations were from physical chemistry. That made me wonder if I could get a similar response by giving a public presentation in Bassam's style but with the demonstrations that I had been using in my course.

The Physics Department had a tradition of sponsoring a public lecture the first Wednesday evening of each month, usually given by someone on the faculty, and they were reasonably popular. Stewart Prager was the chair of the public lectures committee, and he eagerly accepted my offer to give such a presentation in February of 1984, the next open date. I chose '*The Wonders of Physics*' as a title for the lecture. I made a list of about twenty of the best demonstrations, and the publicity went out. I was a bit apprehensive and asked Tom Lovell, who had been a speech major and by then was chief engineer for the plasma group, to introduce me and help out if anything went wrong. I had grown to value his advice and wisdom. We recruited a few others from the plasma group to help with ushering and technical support. The demonstrations were provided by Ken Maas, whose regular job was to maintain and prepare the demonstrations for the physics courses.

On the evening of the lecture, it was clear that we had a problem. Many more people showed up than we could accommodate in our largest lecture room, which seated a bit over three hundred. There must have been another hundred people standing in the back and sitting in the aisles. It was more people that I had ever seen in that room, and surely we were in violation of the fire regulations. All three local television stations and the local newspaper sent reporters with cameras. With at least a hundred more unable to get into the room, we hastily agreed to repeat the 7 pm lecture at 9 pm. Both shows went smoothly, with a response at least as enthusiastic as what I had seen at the chemistry show, although the second presentation was a bit of a letdown with the room only a third filled and the reporters long gone. It was an experience of a lifetime for me. The next day, there was a story about the show with a photo on the front page of the afternoon newspaper, *The Capital Times*.

Immediately afterwards, people began asking when I was going to do it again. It had never occurred to me that it might be a recurring event. I had already done all the best of the demonstrations, and I could not see how to top that. Bassam Shakhashiri had heard reports of the show and invited me to his office to talk about it. I had not met him, and I doubt that he had ever heard of me before that. I told him that I was being encouraged to do it again but didn't see how I could. He told me not to worry about

It's time to plan that spring garden **Off Hours**

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City Final **THE CAPITAL TIMES**

Thursday afternoon, February 16, 1984 — Madison, Wisconsin — Phone 252-6400 Subscriber service 252-6363 30¢

## *UW prof's physics acts electrifying*

By KAYE SCHULTZ
Capital Times Staff Writer

A University of Wisconsin-Madison physics professor got a half-million volt jolt of electricity in his Sterling Hall lab Tuesday evening when he came into contact with a huge transformer coil.

The crowd loved it.

Professor Clinton Sprott usually deals in plasma physics, the stuff of thermonuclear reactions. But he called on the theories of classical physics Tuesday — motion, heat, sound, magnetism and light — in a one-hour demonstration that was intended to outdo, and at least rivaled, the annual chemistry department display.

An audience of more than 400 adults and children gaped and giggled at things that exploded, erupted, boiled, levitated, shattered and vibrated at Sprott's fingertips.

He blinded them with science.

Heather Gutknecht, 7, was literally electrified by a Van de Graaf generator, an apparatus that charged her to 100,000 volts and stood her hair on end. Sprott himself took a larger voltage from a Tesla coil, passing the charge through his body momentarily while illuminating two light bulbs.

There was the climbing arc or Jacob's ladder, a pair of wires resembling TV "bunny ears" that is a standard prop in every mad scientist movie ever made.

(See PHYSICS, Page 6)

SHEILA REAVES/The Capital Times

**Heather Gutknecht, 7, daughter of James Gutknecht, finds that science can make your hair stand on end especially when it's static electricity generated at the University of Wisconsin.**

## Physics

From Page 1

"I don't know of any good use for this thing," Sprott said as a treacherous-looking finger of flame crawled up the gap between the wires. "A king-sized lightning rod," suggested one onlooker.

While a bowling ball on a wire swung precariously close to the face of a volunteer, Sprott explained that "for the physicist, energy is always conserved. It just changes from one form to another." Susan Smith, standing behind the bowling ball pendulum, hoped fervently that it wouldn't change the form of her face.

"How many of you have heard of the Hindenburg?" Sprott asked as he exploded a hydrogen-filled balloon. Had the ill-fated zeppelin been filled with helium instead of hydrogen, it would not have been flammable, he demonstrated with a second balloon.

A "geyser" continuously spewed and snorted in the background, causing first-row spectators to put up an umbrella at one point. There were enough "oohs" for a fireworks display as the lights went down to reveal a prism rainbow and the revelation that chalk dust makes a laser beam visible along its length.

As he demonstrated the difference in sound waves from a tuning fork, music and the human voice on an oscilloscope-TV, Sprott threw in a few insights into the basic theories of physics that may have made Newton wince.

"What makes an object fall? Gravity, right? But does that explain anything, or is it just a word?"

"Just a word!" the crowd responded eagerly.

"Well, a lot of physics is that way," Sprott said. "The laws of physics are very precise in calculating *how* things move and behave, but not why. We know the laws; we understand what's supposed to happen, but we can't always explain it on a fundamental level."

With that, the tuxedoed Professor Sprott disappeared in a self-generated cloud, which, he explained, was made from the room-temperature boiling of liquid nitrogen.

He should have just said it was magic.

Front page of *The Capital Times* the day after the first presentation of *The Wonders of Physics* on February 15, 1984.

repeating the demonstrations. It would be a different audience, and those who came again would want to see their favorite demonstrations. I decided to wait a year and make it an annual event around Valentine's Day, much as Bassam had done with his Christmas lectures. That would also give me time to develop some new demonstrations and plan an even better show without consuming too much of my time.

The next year, we planned for two shows so as not to have to turn people away. Both shows were packed to overflowing, and so we gradually added more shows over the following years and began issuing free tickets. Thus began the annual presentations of *The Wonders of Physics* that continue to this day, now with ten shows over the course of two successive weekends each February, with each show filled to capacity.[1] The shows grew increasingly theatrical with audience volunteers, costumes, live music, skits, and special guests. I always wore a tuxedo, had a funny entrance, and ended the show

[1] Much more information about *The Wonders of Physics* can be found at http://sprott.physics.wisc.edu/wop.htm.

by vanishing in a cloud produced by the rapid boiling of liquid nitrogen.

Publicity photo showing me doing a chaos demonstration in February, 1990.

Although I was having fun and the audiences were large and enthusiastic, not all of my colleagues approved of what I was doing. Some felt that I was 'dumbing down' the science and wasting time that would better be spent on research. One highly respected colleague reminded me that giving lectures to children was not what the Department had hired me to do and warned me that these activities could negatively impact my yearly raises. He was right about that. Another forbid his graduate students to be involved. Other faculty were mildly supportive, and some like Stewart Prager were more enthusiastic. I could never tell how Don Kerst felt about it, but he did attend at least one of the shows with his wife Dorothy, and he designed and helped build an apparatus for levitating an aluminum ball in an ac magnetic field, which turned out to be one of our most popular and unusual demonstrations. As the years went on, I heard less criticism, and most of my colleagues came to realize the value and importance of it, often bringing their children to the shows, but rarely showing much interest in helping with the presentations.

I also began to understand the value of what I was doing in countering the problem of scientific illiteracy and encouraging children to consider careers in science. Many people think I started the program for those reasons, but the justification came along later as I had to defend what I was doing to some detractors and to seek financial support for the program. I justified our approach by contending that our goal was merely to generate excitement and interest in physics and only secondarily to educate, and that continues to be our philosophy. It is rare that an activity with such lofty goals can be so much fun.

I began getting requests to visit schools with the show, and I realized that I needed to be careful not to let this activity eclipse my research and other university duties. I decided to uniformly decline such invitations, in part because it would be a lot of work to pack the equipment, transport it, set it up, and then get it all safely back to campus. Most of the equipment was shared with the lecture courses, and conflicts would arise if I took it off campus for a whole day. Many of the best demonstrations were too large or delicate to move easily. Besides, I needed a supporting cast to make a good presentation, and I could not expect others to neglect their official duties to help, especially during the day when schools are in session. I did agree to do a number of presentations on campus for groups that would come by chartered bus, but even that was becoming a burden, and I made a few exceptions for Founders' Day Groups (Wisconsin alumni) and others.

Then one day, probably around 1986, one of the graduate students, David Newman, who had helped with some of the shows said 'we should take this show on the road.' I said 'David, you don't know what you're suggesting.' But he insisted that he could do it if I wasn't interested, and I told him to give it a try if he really wanted to. He recruited another graduate student of mine, Christopher Watts, and the two of them began visiting schools and doing a superb job, sometimes recruiting other students to help.

I requested and was given a one-time $22,000 grant from the University Office of Outreach Development to duplicate the equipment and to pay some of the costs of putting on the presentations. Thus *The Wonders of Physics Traveling Show* was born and continues to this day.[2] The Office of Outreach Development subsequently wanted to be reimbursed for their support by taking all the money from doneations we requested from those for whom we did shows, but I worked out a compromise where we shared the donations 50/50 with them for the first year.

[2]Much more information about *The Wonders of Physics Traveling Show* can be found at http://wonders.physics.wisc.edu/.

The demand for traveling shows continued to increase, eventually to the point where David and Christopher and the other students could not keep up, and so we hired a quarter-time person, Rich Woodring, using funds we raised from the donations we received. We eventually persuaded DoE to support a half-time outreach person as a supplement to the funding we were getting for plasma research, and Roger Feeley held that job for almost a decade. Shortly afterward, NSF through the Center for Magnetic Self-Organization of Laboratory and Astrophysical Plasmas provided support for another half-time position, and so we were able to hire a succession of full-time outreach specialists—Jim Reardon, Rachael Lancor, Jesse Richuso, Ella Braden, and currently Mike Randall. About a hundred traveling shows are given every year, including all 72 counties in Wisconsin through a grant from the American Physical Society during the World Year of Physics (2005), over thirty states, and five foreign countries (Canada, Portugal, South Africa, Egypt, and Japan).

Meanwhile, I realized that we could expand the reach of the program by videotaping the yearly show that I was doing on campus and distributing the videos to cable television stations, schools, and individuals. The University provided the funding to produce a video of the 1986 presentation (the third year), and a video has been made each year since using funding from a variety of sources. The videos are sold at nominal cost ($25 postpaid in the US) and are now streamed on the Web for free in lower resolution. Beginning in 1990, each show had a theme so that the videos are not too repetitious.

I also began getting queries from colleagues at other universities and laboratories about the program, often saying they would like to do something similar and asking for details and advice. That inspired me to request a small grant from NSF to prepare a *Lecture Kit* that would describe our program and would include a list of the demonstrations with a short description, a sample video, the *Physics Demonstrations* software, and samples of some of the materials we often distributed at the presentations. I wrote an article about the program for *The Physics Teacher* and mentioned the availability of the *Lecture Kit*.[3] Ultimately, about five hundred copies were distributed at $90 each, and we still occasionally get requests for them, even though most major universities and scientific laboratories now have some kind of similar outreach program, often modeled after our own.

Our program came to be widely recognized because of the article in *The*

[3] J. C. Sprott, Physics to the People!, *The Physics Teacher* **29**, 212–213 (1991).

A public presentation of *The Wonders of Physics* in 2002.

*Physics Teacher*, our website, and especially the web-streaming videos. I began getting invitations to take the show to settings all over the world. I would usually refer these requests to our outreach specialist, but some invitations were too attractive for me to turn down, or they were insistent that they wanted me personally. I would usually request a substantial fee (donated to *The Wonders of Physics*) and have our outreach specialist drive a van filled with the equipment to the site of the presentation and set everything up while I flew in at the last minute to do the show. The largest such shows were done in convention centers in Cheyenne, WY and New Orleans, LA. For most of the overseas requests, we would quote them a large cost including shipping all the equipment, and their interest would wane. For the shows that I did in Portugal, Egypt, and Japan, we required that they supply the demonstrations, which worked well and has the added important benefit they are left with equipment to continue their own outreach program.

Bassam Shakhashiri was writing a multi-volume set of *Chemical Demonstrations: A Handbook for Teachers of Chemistry*, the first volume of which had been published by the University of Wisconsin Press, and I decided it would be nice to have something similar for the physics demonstrations that we were using in our public presentations. I wrote about a hundred pages and submitted it to the University of Wisconsin Press, but for reasons that are still not clear, they were not particularly interested in publishing it. I approached a few other publishers who thought the market would be limited since it was aimed at physics teachers rather than students, and so I gave up on the project and eventually put what I had written on the Web in the mid 1990s.

Another few years passed, and Bassam asked what was happening with the book. I related to him the lack of interest I had encountered, and he offered to put in a word for me with the UW Press. It was not long before a contract was signed, and I finished the 300-page full-color book about a year later. As a result, *Physics Demonstrations: A Sourcebook for Teachers of Physics* was published in 2006 including two DVDs showing all 85 of the demonstrations performed before a live audience. A favorable review of the book in *Physics Today* by Richard Berg at the University of Maryland as well as several other reviews resulted in quite a few copies being sold. I doubt that there is enough institutional memory at the UW Press to regret their twenty-year delay in publishing a successful book, and I certainly found other things to do during that time including writing four other books. The final book was probably much better than the earlier version could have been because of advances in digital photography and video production and the many additional demonstrations developed over the intervening years.

Around the time of my retirement in 2008, I became concerned about the future of the program when I was no longer able to oversee it. The traveling show was reasonably secure as long as DoE and NSF continued to fund a person to do the presentations, but the annual shows on campus had grown to be major event requiring considerable effort on the part of many people, all of whom had other duties and volunteered their time for rehearsals and for the entirely of the two weekends in mid February. None of my colleagues in the Physics Department showed any interest in taking it over from me. As a result, I have been trying to extract myself gradually and gently from many aspects of the program while taking care to see that others step forward and play a larger role. It remains to be seen how this will play out, but I have some confidence that the program will continue in some form in my absence as long as there is funding for at least one full-time person for whom this is their prime responsibility. I have made arrangements through my will for long-term financial support of the program.

I'm glad I was home to take that phone call in 1983 and had nothing more important to do than attend a chemistry lecture that December evening.

**TOMMY G. THOMPSON**

**Governor**
**State of Wisconsin**

March 5, 1993

Clint Sprott
UW-Madison
Department of Physics
475 N. Charter St.
Madison, WI 53706

Dear Mr. Sprott:

I was delighted to read of your physics presentation in the February 22 Wisconsin State Journal article.

Your endeavors to educate the community about the principles and wonders of physics further affirms the University of Wisconsin's commitment of quality education and community involvement. I salute you for your efforts and your outstanding work at the UW and within the community.

My highest regards and best wishes.

Sincerely,

TOMMY G. THOMPSON
Governor

TGT/net

A letter from Governor Tommy Thompson congratulating me on the tenth anniversary of *The Wonders of Physics*.

# Chapter 11

# A Night at Sea

> The human heart is like a ship on a stormy sea driven about by winds blowing from all four corners of heaven. —Martin Luther

It promised to be a replay of one of the most enjoyable experiences of my life. My friend and mentor was retired and living in Florida. Seven years earlier, Don Kerst had taken me sailing in the Bahamas in his 36-foot sloop. I'd waited a long time for the chance to go again.

I was so anxious that I flew to Florida a few days early to help get the boat ready. The boat was in excellent condition. On Saturday my enthusiasm mounted as we began motoring down the intracoastal waterway to Fort Lauderdale. We wanted to set sail well south of West End, our first stop in the Bahamas, so as not to buck the Gulf Stream during the 80-mile crossing. The plan was to leave in the evening on Monday, head due east across the Atlantic, and arrive at West End during daylight the next day.

Unfortunately, on Monday there was a strong wind from the east, thunderstorms, and four- to six-foot seas. Under other circumstances, a day on the beach at Fort Lauderdale would have been a treat, but I wanted to get to the Bahamas. Don insisted that we wait for better weather.

On Tuesday the weather had improved slightly, and he succumbed to my restlessness and agreed to try to cross. With the east wind, we would have to use the motor. If we could manage three knots, the trip would take about sixteen hours. At five pm we departed.

On this first attempt, we found the drawbridge over the inlet from the ocean not operating. There was nothing to do but return to the marina and wait for it to be repaired. We finished dinner just as the sun was setting and

Don Kerst's 36-foot sloop, CAVU II.

called to learn that the bridge was operating.

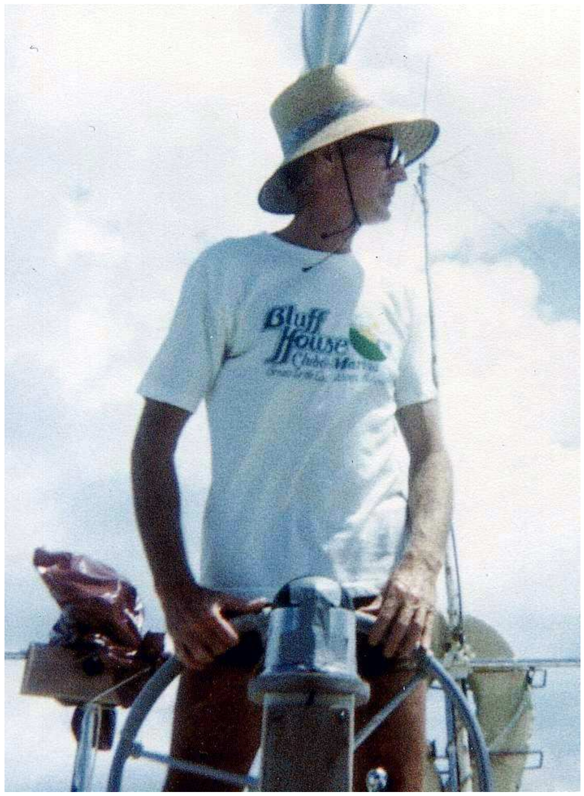
Don had been concerned that the engine was making a strange noise that I could never quite hear. Now he decided that someone should come and listen to it. My impatience grew as he spent the next three hours on the phone unsuccessfully trying to reach a mechanic.

It was almost midnight when we set out again. A few hundred yards out into the ocean, we were bobbing up and down in high waves, fighting a headwind, and making painfully slow progress. Our thirty-five gallons of gas would not get us across to the Bahamas, even if we were willing to spend two days at sea. With disappointment we ended our second attempt.

The next day we were delighted to see improvement in the weather. The wind was still from the east at ten to fifteen knots with two- to four-foot seas. A mechanic came and gave the engine a clean bill of health. We devised a new plan. We would sail to the southeast, toward Bimini and then tack to the north. If we could maintain six knots, the trip would still take about sixteen hours, but the boat would be steadier in the water with the sails up.

At three pm on Wednesday, we began our third attempt. It was a rough, wet ride. It took great effort just to hold on and not be washed overboard. We wore safety harnesses. But we were making good time, and it appeared that our plan was working. Don and I took turns at the helm.

The first indication of trouble came about four hours out at sea. The




Don Kerst at the helm of CAVU II.

wind died down briefly. When we tried to use the engine, it was missing on several cylinders because of the salt water bath it was taking. Don managed to get the engine running, but it was to be a continual concern.

With the tall condominiums along the coast disappearing and darkness setting in, I went below to take the first radio fix of our position. Before I could finish, I heard a loud noise and went above deck to find one of the sails, the jib, down on the deck. The three-sixteenth-inch steel cable, the halyard, that attaches it to the mast had broken. It took nearly an hour to get it stowed. With only the mainsail, our progress was slow. Darkness was upon us, and we were uncertain of our position.

I went below to take another radio fix. Without the horizon in sight and with the boat still rocking severely, seasickness began to set in. I confessed my predicament to Don and suggested that he take the fix while I steer. Unfortunately, focusing on the compass with the horizon obscured by darkness and the lights from below deck, my sickness quickly became acute. I lunged for the side of the boat. Having never been seasick, I was unaware that one should avoid the windward side of the boat. A gallon of fresh water was required to clean up the mess.

After a few minutes, I felt better and managed to hold the course while Don established our position. Although I desperately wanted to continue to the Bahamas, Don felt that repairs could better be made in West Palm Beach, and at ten pm we reversed our course.

In addition to nausea, I now felt disappointment, embarrassment, and helplessness. With clear skies and the wind at our backs, we were maintaining a good speed, and I asked Don if he could manage alone while I took a nap. He thought so. West Palm Beach was four hours away.

It must have been an hour later when I was awakened by a loud noise. The sail had jibed. I went above deck to help. We were in a severe thunderstorm with sheets of rain, lightning all around us, and the sail whipping uncontrollably. I must have been sleeping soundly because Don said this was the third such squall he had been through since I had gone below.

I still felt sick but knew I had to help. The mainsail was collecting bags of water which I was able to empty. The rain poured as from a shower at full blast. Fortunately, the rain was warm. The temperature was about seventy-five degrees, and I was comfortable in my swimsuit and waist-length, hooded raincoat. Lightning and thunder crashed all around us. We avoided touching metal parts of the boat and feared a direct lightning strike on the mast. The boat rocked and rolled to an extent I didn't think possible. Black clouds loomed in every direction. We kept changing our course, but there was no escape from the fury of the storm.

The sail swung wildly. On one occasion, the ropes attached to the boom hit me so hard on the right side of my head that I reached to feel whether my ear had been torn off. It was still intact, and the pain quickly subsided, but the flashlight I was holding no longer worked. It was then that we noticed a rip in the mainsail.

Don suggested it was time to call the Coast Guard. That was the first indication he had given that we may not make it on our own. I took the helm while he went below to the radio. It was two am. I could hear only bits of the conversation. A woman's voice kept requesting our position. It was comforting to know someone was aware of our plight. We had sailed for several hours in various directions without a radio fix. We could see lights on the coast and thought we were near West Palm Beach. The Coast Guard helped determine our position but did not volunteer to rescue us despite the desperation in Don's voice. They asked us to call every fifteen minutes to advise them of our progress. Meanwhile, I struggled to keep the boat upright, on a westerly heading, and with enough wind to keep the sail from ripping further.

Finally we spotted the red and green flashing lights on the buoys that mark the entrance to the harbor. We felt great relief and turned into the wind to lower the sail. Then we saw lights from a nearby boat and maneuvered to get out of its way. By the time we had reestablished our heading, we had lost sight of the buoys. In the few minutes that had passed, the Gulf Stream had swept us far north of the inlet. Our feeling of desperation returned.

With the engine at full power on a southerly heading, we watched in astonishment as we slowly drifted backwards. I turned us to a southwesterly heading to get closer to shore where perhaps the current would be less. For a while, we drifted even faster backwards, but eventually we began to make some progress. We were about half a mile from the shore.

As we got closer to shore we worried about depth, lest we run aground and sink the boat. The depth sounder behaved erratically, and we assumed it had been damaged by lightning. We felt that nature was conspiring against us.

For at least another hour, the small thirty horsepower motor strained against the current. Progress was almost imperceptible. The Coast Guard kept calling to check our progress.

About four am we finally spotted the buoys again and felt that our ordeal was nearly over. This time our eyes were riveted to the flashing lights. As we got closer, the waves and current subsided, and we were soon motoring up the inlet. We reached a quiet spot and dropped the anchor in water that by contrast had not a ripple. With the light of dawn just beginning to appear, we were asleep within minutes.

The next thing I remember, Don was rustling around in the cabin. It was 8:30 am. My sickness was gone. We had spent thirteen hours in the Atlantic and felt lucky to have avoided a serious disaster.

A boat came by and asked us to move so that a freighter could maneuver. We motored another hour up the waterway to a marina where, by coincidence, the boat had been built. We relived the experience as we inspected the damage. Don was only half joking when he quipped that perhaps the man who built the boat would offer him a good price for it. I made reservations on the first flight home and stayed another two hours to help tidy up the boat.

My taxi for the airport came at two pm. As I said goodbye to Don, I told him to let me know if he wanted me to return for another try in a few weeks. He nodded. But beneath the facade of interest, I secretly hoped that it was a decision that would not have to be made too soon.

# Chapter 12

# An Encounter with Chaos

> God doesn't play dice with the Universe. —Albert Einstein
>
> Quit telling God what to do. —Niels Bohr
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> Chaos is the law of nature, and order is the dream of man. –Henry Adams

In 1988 I was feeling restless. I had worked on a number of plasma confinement devices—the Toroidal Octupole, the Levitated Octupole, the mirror device in Electrical Engineering, the Elmo device at Oak Ridge, the bumpy torus, Tokapole I and II, and now the MST device was finished and making reversed field plasmas. Although I enjoyed designing, building, upgrading, and optimizing these machines, I had limited patience for the years of work that follows in extracting data from them. I had relinquished the duties of principal investigator to Stewart Prager, we had only the one MST device, and Stewart was clearly in charge. My mentor Don Kerst had moved permanently to Florida. I was getting most of my satisfaction from working with computers, but I was running out of good problems to solve with them. In addition, I was devoting considerable time to *The Wonders of Physics* outreach program. I was growing slightly bored with plasma physics and was ripe for a change, but I didn't know in which direction to turn.

Spending his sabbatical with us that year was George Rowlands, an older and quite congenial theoretical physicist from the University of Warwick in England. I knew he was working on nonlinear dynamics, about which I knew little, and I was an experimentalist and had never been very successful interacting with theorists, especially ones who worked on abstract problems rather than those directly related to our experiment. I avoided interacting with him scientifically for the first eight months of his sabbatical. I was sure that we would have little in common especially after he wandered into the MST control room one day where I was running an experiment and declared that he had better leave before he broke something.

Me with my mentor, friend, and colleague, George Rowlands.

Then toward the end of the academic year, he spoke at the physics colloquium about his work. I had attended the weekly colloquium almost every Friday afternoon for the previous twenty-five years, and most of the talks were rather boring. I had little expectation that this one would be any different. Speakers usually show fancy slides for such an occasion, but George just sketched a few things on the chalk board and talked in his colorful way. I was captivated by his words. He was talking about simple ideas related to chaos and fractals that I had somehow escaped knowing anything about. It was like a breath of fresh air—a new way of looking at the world.

After the lecture, I said to him, ‘George, that was a great lecture, but you need some computer animations to illustrate the ideas.’ I had recently written a simple package of physics demonstration programs illustrating some of the concepts I used in *The Wonders of Physics*, and they were being marketed by Physics Academic Software. I was primed to do something similar but at a higher level. I offered to write some animations if George would teach me the science. We worked hard for the next few months until his sabbatical was over and completed a first version of *Chaos Demonstrations* which was subsequently marketed by Physics Academic Software and won the first annual *Computers in Physics* software contest for the best educational software of the year in the chaos category. I had found a new scientific direction that effectively exploited my computer interests and skills.

George and I continued to collaborate by email and FaX and occasional visits. One of his research interests was to take a time series from an experiment such as magnetic fluctuations in our plasma device and fit the data to a simple model equation that had the possibility of producing chaotic solutions, and thereby learn something about the processes producing the fluctuations. By working with him on that topic, I was able to rationalize that what I was doing had some relevance to the plasma physics grant that was still funding my summer salary and a couple of my graduate students. With his guidance, I developed another set of programs, *Chaos Data Analyzer*, that was later marketed by Physics Academic Software and became one of their top revenue producers. It was purchased by a wide variety of users including Wall Street investors trying to get the edge on the competition by making better predictions of financial markets.

For the uninitiated, I should explain that chaos is the apparently random behavior of a deterministic system. The behavior is governed by rules, but the result is a random-looking, continuing fluctuation that never repeats and that is extremely sensitive to the starting condition. The effect was first discovered in modern times (1959) by the MIT meteorologist Edward Lorenz, who dubbed it the 'butterfly effect' since a butterfly flapping its wings in Brazil can change the state of the chaotic atmosphere sufficiently to cause a tornado in Texas a few weeks later, making long-range weather prediction impossible. Even more amazing is that such behavior can occur in extremely simple equations. Since the equations can only be solved by computer, I had found the perfect application of my computer skills.

We were not successful in finding a set of equations whose behavior replicated the plasma fluctuations. The equations would provide good short-term prediction, but their long-term behavior was typically not even chaotic even when we fit the model to simple data known to be chaotic. The solutions would usually settle down to a stable equilibrium, cycle periodically, or wander off to infinity. One of my graduate students, Christopher Watts, did his PhD thesis analyzing the fluctuations in MST using methods similar to those in the *Chaos Data Analyzer* program, and he was unable to find any evidence of chaos in the fluctuations; instead they appeared to be random.

Thus it was becoming increasingly difficult to justify my new interest by its relevance to our plasma research. I still didn't know enough about the subject to do any serious chaos research. My colleagues suspected that I had given up physics and was off playing computer games, writing commercial software, and putting on shows for school children, an impression that plagued me for the rest of my career. I had no collaborators in the Physics Department, and no one knew or understood much about what I was doing. My yearly raises were dismal, since my colleagues thought I had turned my back on the successful program in plasma physics that I had recently led. It was a difficult time professionally, but I was having fun and learning many new things, and I was certainly still interested in physics, although I could see the applications of my new interests extending to many other fields such as economics, ecology, and meteorology.

Two related observations intrigued me. I wondered how I could have gotten that far in my education without knowingly encountering an equation with chaotic solutions, and I wondered why it was so difficult to find a chaotic model to fit chaotic data, although I subsequently realized that a computational study I had done two decades earlier was probably an example of chaos.[1] I decided that chaos must be an extremely rare phenomenon in simple systems of equations.

That suggested the first serious research problem in this new area for me. I would feed millions of different equations into the computer and record what fraction of them had chaotic solutions. Was it one in ten, one in a thousand, one in a million? I had no idea. It was a simple concept, and easy to program, but the computations took many weeks on the personal computers available in 1990. But I got an answer. Depending on the class of equation and the way its parameters are constrained, the answer is a few percent. Chaos is the exception in simple equations, but it is not exceedingly rare.

I was excited about my new result and submitted it to *Physical Review Letters*, the premier journal for exciting new results in physics. The reviews were scathing, one saying that I was apparently a new graduate student working alone without faculty supervision. I was well published and well known in plasma physics, but I had entered a new field where no one knew me, and I had yet to master the jargon that every subfield of physics has.

[1] J. C. Sprott, Numerical Calculations of Off-resonance Heating, *Physics of Fluids* **15**, 2247–2253 (1972).

The paper sounded amateurish, but I eventually got it published in *Physics Letters*,[2] a slightly less prestigious European physics journal.

Looking at a million equations and finding a few percent that are chaotic meant that I had 'discovered' thousands of previously unknown chaotic systems. Papers in the literature usually studied the same handful of well-known examples because no one had done such an extensive search before. Thus I was able to publish the method and some of the new cases I had discovered in the journal *Computers and Graphics*.[3] That got the attention of the prolific author and IBM scientist Cliff Pickover who edited the *Chaos and Graphics* section of the journal, and thus began a long-term friendship and occasional collaboration. He was intrigued by my methods and wrote that he had rarely enjoyed reading a paper as much as mine. My confidence was starting to build.

I began looking for other applications of my brute-force method. I wondered if there were chaotic systems of ordinary differential equations that were simpler than the ones that had been discovered by Lorenz in 1963 and later by Otto Rössler in 1976 that everyone was using as the prototypical examples of chaos. I set the computer to the task and found nineteen such systems. That work was published in *Physical Review E*[4] in 1994 and is one of my most cited publications. In 1997, I found and published an even simpler system,[5] called a 'jerk system' because of its third derivative that still holds the record.[6] In fact, it has now been proved that there can be no simpler system.

That prompted Hans Christian von Baeyer to write a flattering article entitled 'All Shook Up: The jerk, an old-fashioned tool of physics, finds new applications in the theory of chaos' in *The Sciences*, a journal of the New York Academy of Sciences.[7] The renown applied mathematician Steve

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[2] J. C. Sprott, How Common is Chaos?, *Physics Letters A* **173**, 21–24 (1993).

[3] J. C. Sprott, Automatic Generation of Strange Attractors, *Computers & Graphics* **17**, 325–332 (1993).

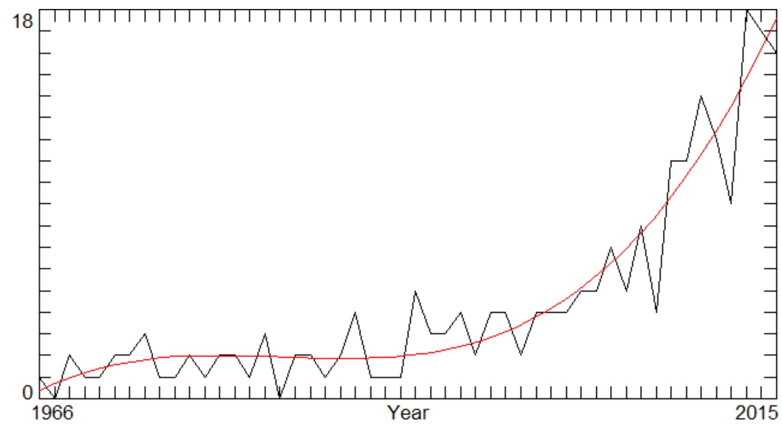
[4] J. C. Sprott, Some Simple Chaotic Flows, *Physical Review E* **50**, R647–R650 (1994).

[5] J. C. Sprott, Simplest Dissipative Chaotic Flow, *Physics Letters A* **228**, 271–274 (1997).

[6] The simplest ordinary differential equation with chaotic solutions appears to be $\dddot{x} = \dot{x}^2 - A\ddot{x} - x$, where the overdot denotes a time derivative and $A$ is a constant in the vicinity of 2.02. The 'jerk' is the time derivative of acceleration, which is the time derivative of velocity, which is the time derivative of displacement.

[7] H. C. von Baeyer, All Shook Up: The jerk, an old-fashioned tool of physics, finds new applications in the theory of chaos, *The Sciences* **38**, 12–14, (1998).

Strogatz calls me ‘the jerk guy.’ Efforts to find the simplest chaotic system of various types eventually led to the book *Elegant Chaos: Algebraically Simple Chaotic Flows* published by World Scientific in 2010.




A record of the number of my peer-reviewed papers published each year since 1966 with a third-order polynomial fit in red. The notch from 1988–1990 corresponds to the construction of MST and to my learning the new field of chaos, and the increase after 2008 corresponds to my retirement.

That trickle of early papers after several barren years of learning a new field slowly turned into a torrent of publications, dwarfing anything I had done as a plasma physicist. My interests ranged widely including subjects such as art, aesthetics, fractals, neural networks, chaotic electrical circuits, magnetospheric fluctuations, self-organized criticality, forestry, ecology, economics, physiology, hedonics, and social psychology. No problem was too far afield if it involved chaotic dynamics, and people from many fields were anxious to collaborate with a physicist who can mathematically model systems and evaluate their behavior—and in many cases correct and improve their English.

Publications are an important measure of the productivity of a scientist, and my rate of publication increased dramatically and continually after I switched from being an experimentalist to a computationalist. In part, this reflects the relative ease of doing experiments on the computer instead of using actual hardware that takes much time and effort to build, maintain, and modify. As my colleague Paul Quin once quipped in a Physics Department faculty meeting, experimentalists are at a distinct disadvantage relative to their theoretical colleagues because ‘they actually have do something before they publish.' It was a witty comment that provoked laughter, but no one disputed it. Computation has become the third leg of research in physics, consisting of experiments in which the only required hardware is a computer. I do feel that I have been more productive in my new field and had more of an impact than I would have had if I had continued to do conventional plasma experiments, although I occasionally returned to my roots in the laboratory.

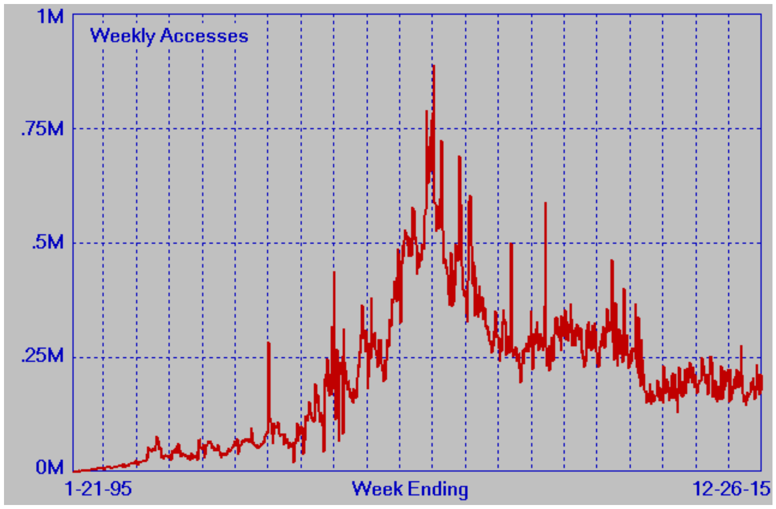
For example, I developed some new chaotic circuits, one of which was mass produced by Ken Kiers and his students at Taylor University and marketed by PASCO for student laboratory use and lecture demonstrations. I had suggested to the Wisconsin Alumni Research Foundation (WARF) that they patent an earlier version of the circuit which might someday find its way into every telephone for speech encryption, but they didn't think it would generate sufficient revenue. Only time will tell.

One of the new chaotic circuits that I invented and that was marketed by PASCO.

I was also intrigued by the World Wide Web and had not only what was probably the first website in our Physics Department in 1994, but probably its first web server and one of the first on campus, a Gateway PC that sat on the desk in my office, and was thus dubbed 'Sprott's Gateway.'[8] That was before there were internet service providers and web hosting services, or at least before I was aware of any. I put many of my publications and other technical materials on the server, and traffic grew rapidly at least until

[8]Sprott's Gateway is at http://sprott.physics.wisc.edu/.

2006, which I interpret as the date at which the amount of web material began growing faster than the amount of web use. That web exposure lead to many research collaborations with scientists from around the world, many of whom I have never met.




Traffic to Sprott's Gateway for the first twenty years.

One way to learn a new field is to teach a course in the subject. Since no such course was being taught at the time, I proposed to teach one on Chaos and Time-Series Analysis in 1994 in addition to my normal teaching assignment of General Physics. I was overwhelmed by the response. Sixty students signed up, representing over twenty departments, and ranging from a freshman English major to the Dean of the Graduate school who sat in on some of the lectures. I repeated the course in 1997 and again in 2000, but with a decreasing enrollment because the excitement over this new field was abating, and other courses on chaos were being taught in Mathematics and in Engineering.

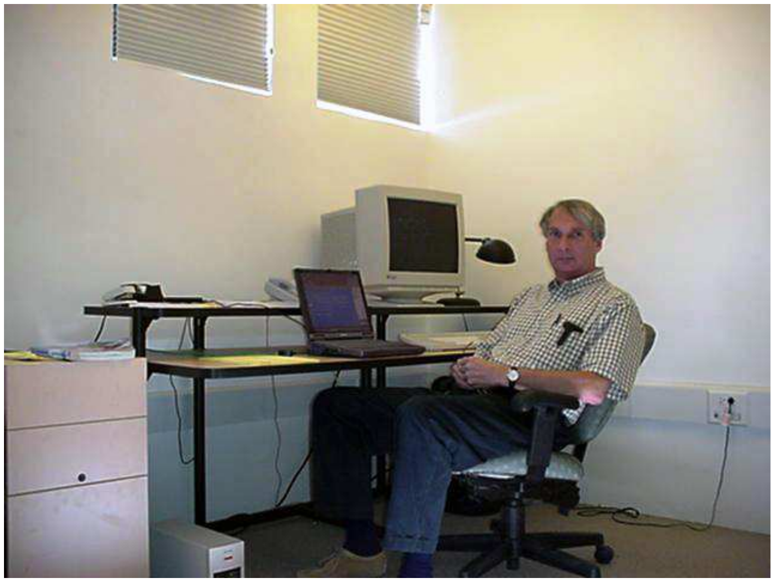
That was one of the first courses at Wisconsin to make extensive use of the Web. All my lecture notes were posted there in detail. That prompted an inquiry from Rufus Neal, an editor with Cambridge University Press, about whether I would like to expand those notes into a book. It was an intriguing idea, and I prepared a proposal, an outline, and a few sample chapters. It was sent out for review, but the reviewers were not enthusiastic since there were already many similar books on the market.

By that time I was mentally committed to writing a book, and I sent the proposal to a few other publishers and got three offers, the most attractive of which was from Oxford University Press, who has the copyright on the Scofield King James Version of the Bible. I figured if OUP was good enough for God, it should be good enough for me. There followed three years of hard work and much learning, before the 507-page *Chaos and Time-Series Analysis* was published by Oxford in 2003. It may always remain my most ambitious work, and it firmly established my credentials in the field, although it was never widely adopted as a textbook.

In the summer of 1994, I got an unusual phone call. It was John Wiley, Dean of the Graduate School. I rarely get phone calls from deans, and I first assumed I was in some kind of trouble. He said he would like to take me and Blake LeBaron out to lunch. Blake was a bright young professor in the Economics Department who had just spent a year sabbatical directing the economics program at the Santa Fe Institute (SFI), a private, not-for-profit, independent research and education center founded in 1984 for multidisciplinary collaborations in the physical, biological, computational, and social sciences which I later visited. It happened that John Wiley had picked up the book *Complexity* by Mitch Waldrop (who coincidentally was a PhD graduate of our Physics Department as was also John Wiley) at the airport to read on the airplane. The cover of the book proclaimed 'If you liked *Chaos*, you'll love *Complexity*.' *Chaos: Making a New Science* was a popular account of the subject written by James Gleick in 1987 and is often credited with bringing the subject of chaos to the awareness of the public. *Complexity* was basically a history of SFI and the new science that was being formulated there and elsewhere.

John thought that our university should be doing something with complexity along the lines of what was being done at SFI. Blake and I had been discussing the same issue, and we were primed to ask John to give us some funds to bring in outside speakers for a seminar series that we called 'Chaos and Complex Systems.' I recall Blake saying that he was willing for the name to have one buzz word (chaos), but that two (chaos and complexity) would be over the top.

That seminar started in the fall of 1994 with $5000 of seed money from the Graduate School and continues today even though Blake left the University to take a job at Brandeis University after the first couple of years to be closer to his new wife who had an appointment at MIT. John Wiley was an active participant in the seminar until he became Provost and eventually Chancellor of the University. I continued to organize the seminar mainly with the help



Me in my office at the Santa Fe Institute in 2000.

of Robin Chapman, an emerita professor of communicative disorders and a long-term friend. One outcome of that seminar was a coffee-table book that Robin and I wrote called *Images of a Complex World: The Art and Poetry of Chaos* that was published by World Scientific in 2005 and that contained her poetry and my computer images and mathematical definitions along with a Foreword by Cliff Pickover who got me interested in computer graphics through his example and encouragement.

The move from plasma physics to the study of chaos and complex systems turned out to be a satisfying one, bringing me into contact with researchers and topics far from traditional physics, and allowing me to exploit my computer skills, publish extensively, and establish strong credentials in this burgeoning field. Meanwhile fusion energy is still a few decades away, just as it was when I began research in that area in 1964. I don't agree with the detractors who say that 'fusion is the energy of the future—and always will be,' but I'm glad to be working in an area where progress is rapid and the problems are more surmountable. Furthermore, since the only equipment one needs is a personal computer, I fully expect to continue research in this area for the rest of my life, with retirement enhancing rather than diminishing my effectiveness, as has proven to be the case in recent years.

# Chapter 13

# Strange Attractors

> Art is a collaboration between God and the artist, and the less the artist does, the better. —Andre Gide
>
> Art is either plagiarism or revolution. —Paul Gauguin

Let me say from the outset that I know nothing about art. I can barely draw a straight line, much less a recognizable drawing of something. I find art museums a bit tedious, and I would be hard pressed to identify the artist for most well-known paintings. I have limited ability to distinguish what others consider good art from mediocre works. Yet this is a tale of how I came to author an art book and sell some of my works to serious art collectors, as well as to publish papers on aesthetics. I initially titled this chapter 'The Accidental Artist,' but I decided the current title would be more intriguing and perhaps more honest since I still do not consider myself a real artist.

I did not set out to produce art; rather it was an unintended but delightful byproduct of my chaos research. My initial foray into the field of chaos was to quantify the likelihood that a simple equation chosen at random would have a chaotic solution. In 1990, personal computers were just becoming powerful enough to address this question through a brute-force search. After running millions of cases over several months of continuous computing, I was able to find that a few percent are chaotic. The computer could be programmed to test for chaos automatically and to record the conditions under which the chaos occurred in a compact form, initially only eight bytes for each case found. Eight bytes corresponds to $256^8 \approx 2 \times 10^{19}$, which allows an astronomical number of cases even when only a few percent are chaotic. To verify that the computer was correctly identifying chaos, I made plots of the solutions of some of the chaotic cases. As expected, they were complex patterns, like snowflakes, no two of which were exactly alike.

The mathematical term for these geometrical objects is ‘strange attractors.’ The noun ‘attractor’ refers to an object (called a ‘set’ by the mathematicians) toward which a wide range of initial conditions within the ‘basin of attraction’ are drawn as time advances. The attractor is ’strange’ because it is a fractal, which is an object with self-similar structure on even the smallest scale and a dimension that is not usually an integer. It is neither a finite collection of points (zero dimension), nor a finite number of lines (one dimension), nor a finite number of curved surfaces (two dimensions), nor any larger integer dimension. In one of my favorite metaphors, Ruth Richards calls fractals ‘the fingerprints of chaos,’ although they can be produced in many other ways.

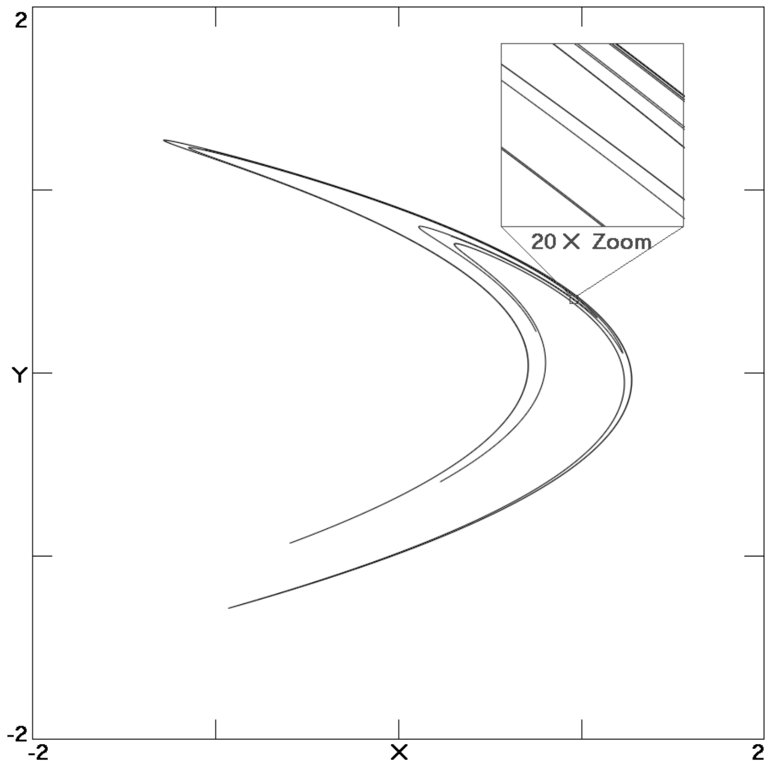
Rather than continue to discuss the mathematical characteristics of a strange attractor, it is more instructive to show an example such as the well-studied Hénon map[1] in the figure, whose dimension is about 1.26. It is neither a long line (one dimension) nor a surface with holes (two dimensions), but somewhere in between. This particular example comes from repeated iteration of the simple system of equations given by

$$\begin{aligned} x_{n+1} &= 1 - 1.4x_n^2 + 0.3y_n \\ y_{n+1} &= x_n. \end{aligned}$$

Start with any (small) combination of $x$ and $y$ ($x = y = 0$ will suffice), plug those values into the equations as $x_n$ and $y_n$, and use the equations to calculate the new values $x_{n+1}$ and $y_{n+1}$, which are then plugged back into the equation in a kind of mathematical feedback. Millions of iterations with each dot plotted at the corresponding location in the $xy$-plane produces the Hénon attractor shown in the figure. The orbit continues to move about on the attractor forever in a chaotic fashion, never repeating but producing a different sequence of dots for each choice of initial conditions.

Now imagine repeating the process for a slightly more general form of the equations, perhaps with a few more terms and with random choices of the coefficients such as the 1.4 and 0.3 above. Most cases just settle to a fixed value or oscillate periodically between a small number of distinct values (a point attractor) or wander off to infinity, but others produce strange

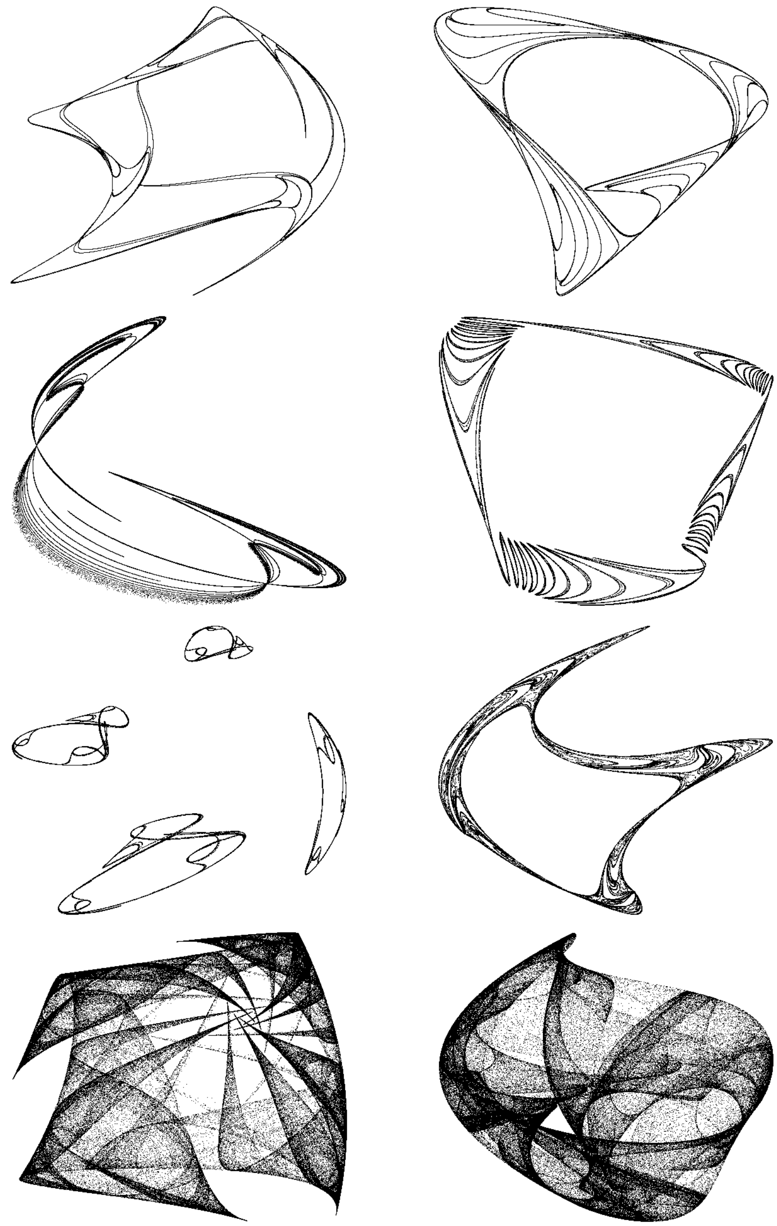
[1] M. Hénon, A Two-dimensional Mapping with a Strange Attractor, *Communication in Mathematical Physics* **50**, 69–77 (1976).




The Hénon attractor is a famous strange attractor with a dimension of about 1.26 from a prototypical chaotic system. The self-similar fractal structure is evident in the 20× enlargement.

attractors, a few samples of which are shown in the second figure using the graphics capabilities commonly available in 1990. Even to my untrained eye, it was evident that these objects had a certain aesthetic appeal, and I knew I could generate an essentially unlimited number of similar but different ones.

I showed some of these images to an undergraduate art major who was working in our plasma lab, and she confirmed that they had some artistic merit and suggested I show them to Professor Ted Pope in the Art Department who had an interest in algorithmic art, which is art produced mathematically. I called Prof. Pope and asked if he would come to my office and have a look, and he agreed. When he arrived, I had the floor of my office covered with strange attractors produced using a crude monochrome dot matrix printer typical of that era. He stared at them for a long time, and just when I was about to conclude that he was going to ask why I had



A collection of strange attractors from a single quadratic map with different choices of coefficients.

wasted his time, he turned to me and said 'if you put these in a portfolio, the Art Department would want to hire you.' I later realized that it was his nature to be complimentary and encouraging, but it gave me confidence to pursue the artistic aspect of my chaos research.

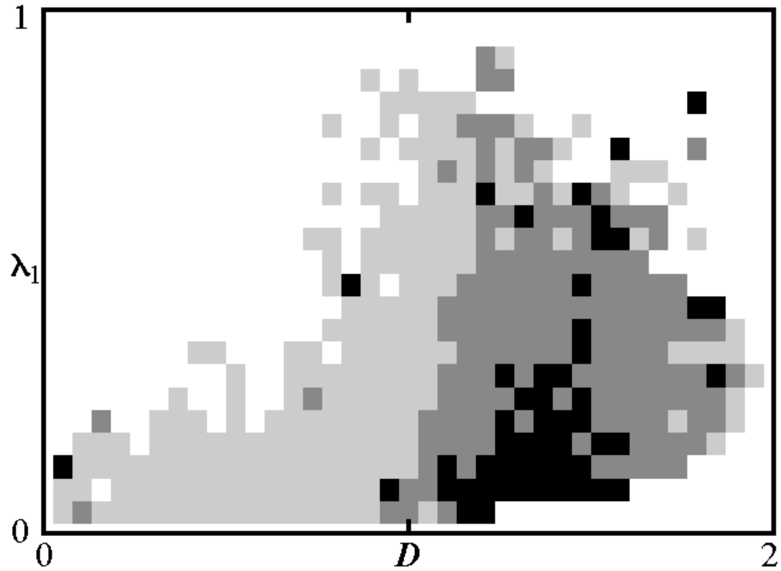
He suggested that I write a book describing the method and showing examples, which I did. In 1993, the book *Strange Attractors: Creating Patterns in Chaos* was published by M&T Books. It contained over 350 examples of strange attractors and the software for producing infinitely many more. It was at the time surely the world's largest collection of strange attractors. The book was in part aimed at the scientific community who seemed to be fixated on a small number of chaotic examples such as the Hénon map. The book also described methods for visualizing attractors in dimensions higher than two (more than just the two variables $x$ and $y$) using color and red/blue 3-D glasses.

It seemed quite remarkable that I had inadvertently programmed the computer to explore millions of equations and automatically identify solutions that had aesthetic appeal, but it was also clear that not all strange attractors were equally appealing. I wondered if I could do even better by training the computer to identify the subset of strange attractors that humans would find most appealing. In essence, the computer would not only be an artist, but it would become a critic of the art that it produced. I later came to understand that some artists were dismissive of the idea that a machine can produce art, but others, like Ted Pope, simply viewed the computer as another tool in the hands of the artist.

My idea was to display a succession of about a thousand random strange attractors on the computer screen to human subjects who would rate each one aesthetically on a scale of one to five by pressing the corresponding key. I would then see if their preferences correlated with mathematical quantities that could be easily calculated for each image such as the fractal dimension and Lyapunov exponent, which is a measure of the sensitivity to initial conditions. The results combining the preferences of eight volunteers are shown in the figure that was published in the *Strange Attractors* book and in a peer-reviewed paper at about the same time.[2] Remarkably, the preferences were clustered in a region of small Lyapunov exponent and intermediate fractal dimension, which allowed me to refine the search program to select only the

[2] J. C. Sprott, Automatic Generation of Strange Attractors, *Computers & Graphics* **17**, 325–332 (1993).

very best images.




Aesthetic evaluation of 7500 strange attractors by eight subjects with the darker regions indicating the preferred values of the Lyapunov exponent ($\lambda_1$) and fractal dimension ($D$).

In this way, I was able to automate the production of a 'Fractal of the Day' on my web Fractal Gallery, which is usually on the first page and is currently the ninth of fifteen million pages returned by a Google search for 'fractals.'[3] I also wrote a Java Applet for the Web that produces a new strange attractor every five seconds for as long as one cares to watch.[4] This was the first and probably the last Java program I will ever write because the learning was slow and painful and the result was not overly satisfying.

When I had asked volunteers to evaluate the attractors, I noticed that the three artist subjects (two graduate students in the Art Department and a former art history major) had somewhat different preferences than the five scientist subjects (mostly physics graduate students). The artists seemed to prefer attractors with higher fractal dimension, which I supposed reflects the tendency of artists to be more tolerant of complexity than scientists who tend to see beauty in simplicity. I subsequently collaborated with a psychologist, Debbie Aks, in an attempt to test this hypothesis with a larger group

[3]Sprott's Fractal Gallery is at http://sprott.physics.wisc.edu/fractals.htm.

[4]The Java search applet is at http://sprott.physics.wisc.edu/java/attract/attract.htm.

of subjects (twenty-four mostly undergraduate students in her introductory psychology course) and with independent measures of creativity. Although the results were less clear, it did lead to a peer-reviewed publication in an aesthetics journal[5] and launched an area of research that others subsequently pursued.

I also became interested in making large prints of some of the strange attractors for wall display. We had in the plasma lab a Hewlett Packard plotter that would make plots on a three-foot-wide roll of paper of any length using up to eight different colored ink pens. It would take overnight to make one 3-foot by 4-foot image, but I made several for display in the Physics Library and a few more for display at home. The art coordinator for the University of Wisconsin Hospital bought some for display in the Hospital. I spent a lot of money buying ink pens for the plotter, and I soon grew tired of making prints and returned to more scientific pursuits.

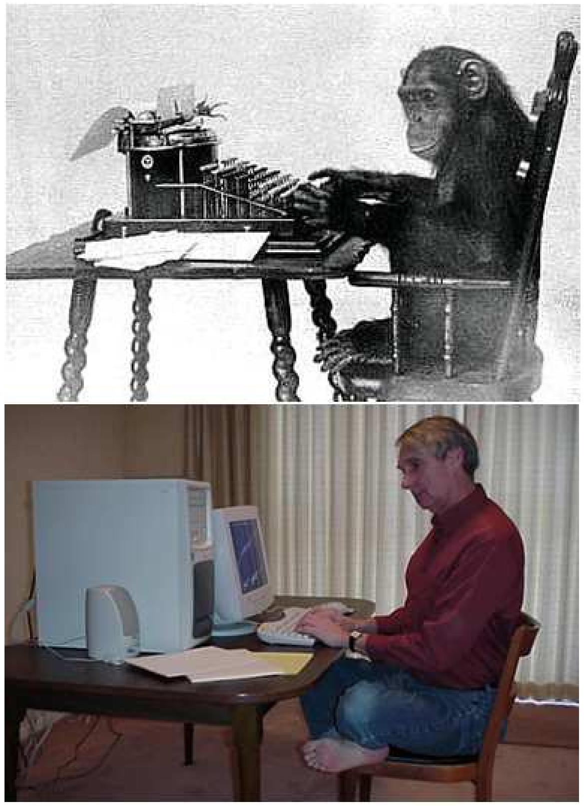
About ten years later, the plasma group acquired an ink jet printer that could make the same large prints in just a few minutes each and with much higher resolution in millions of colors. Meanwhile, computers had become much faster, and I had learned many new techniques for producing fractal patterns. Thus my interest in computer art was revived for a brief time, and I made many new, much nicer prints. I replaced the low quality prints on display in the Physics Library and made some for a local art gallery and many more as gifts for friends.

One of the features of the method is that since it is just as easy to generate a completely new image as to reprint an old one, each print is one-of-a-kind, and then it is retired. Thus the prints might be expected to have considerable value. It has long occurred to me that there would be a business opportunity for someone who could contract with a hotel chain to produce an original print for every room in the hotel. This is not something I plan to pursue, but I would be willing to be a consultant or partner in such a venture.

However, I did have an idea for a coffee table book with my images and the poems that my colleague Robin Chapman had written in response to talks that we heard over the years in the Chaos and Complex Systems Seminar. I also provided some definitions of mathematical terms and an explanation of the methods used in the book. We spent over a year seeking a publisher before World Scientific agreed to publish the book, which we titled *Images of*

[5]D. J. Aks and J. C. Sprott, Quantifying Aesthetic Preference for Chaotic Patterns, *Empirical Studies of the Arts* **14**, 1–16 (1996).

*a Complex World: The Art and Poetry of Chaos*. Some of the images from the book are reprinted here.



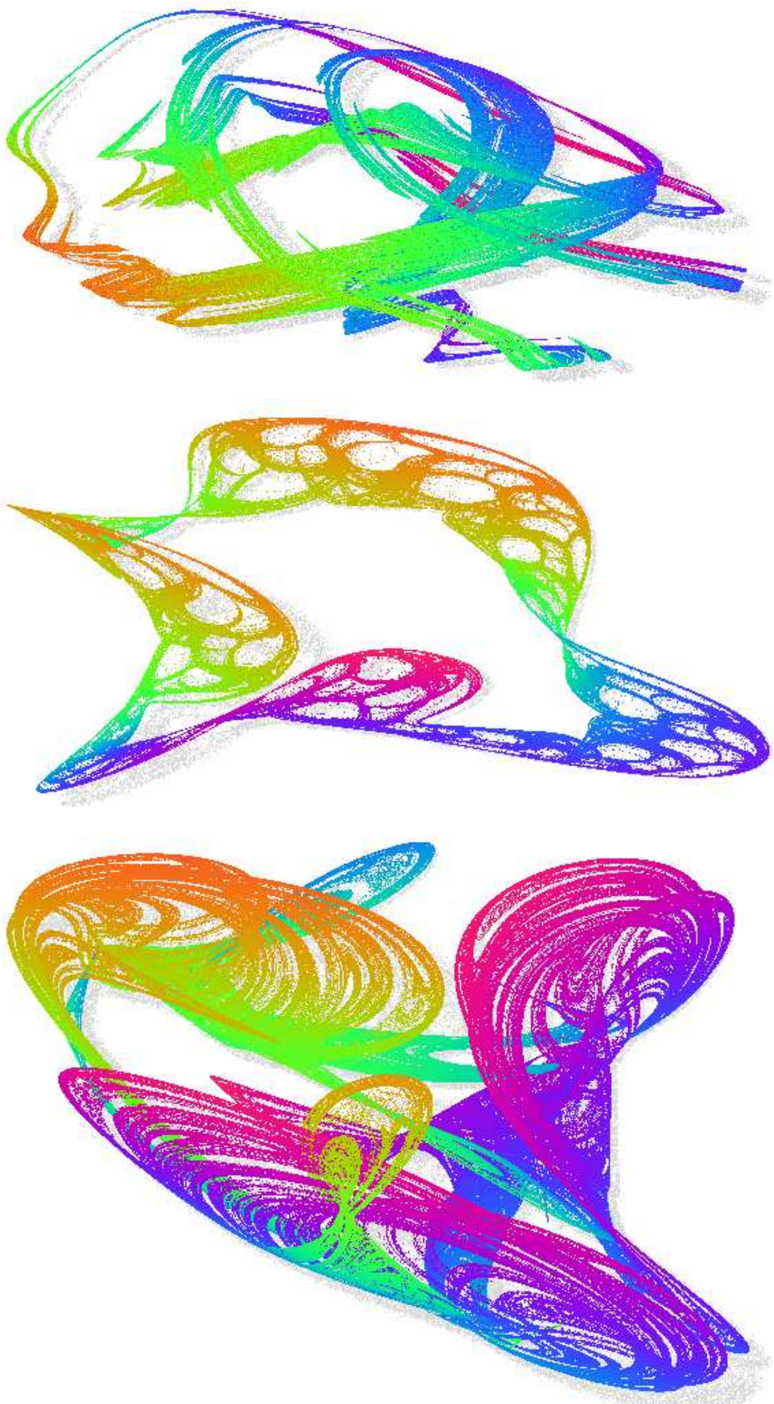
A monkey with a computer creating art.

Of course strange attractors are not the only way to produce fractal images, but they are the ones whose automatic generation I pioneered. Much earlier, others produced stunning images of zooms into the Mandelbrot set and its corresponding Julia sets, and iterated function systems have also been used to produce realistic fractal scenery. Other people such as Paul Carlson, whose Fractal Gallery I host on my web server,[6] invented several novel visualization techniques, and Ian Stewart described methods for producing symmetric images which he called 'icons.' It was natural that I adapted my automatic search methods to these types of fractals as well, and my Fractal of the Day shows many such examples, some of which are included in *Images of a Complex World* and are reproduced here.

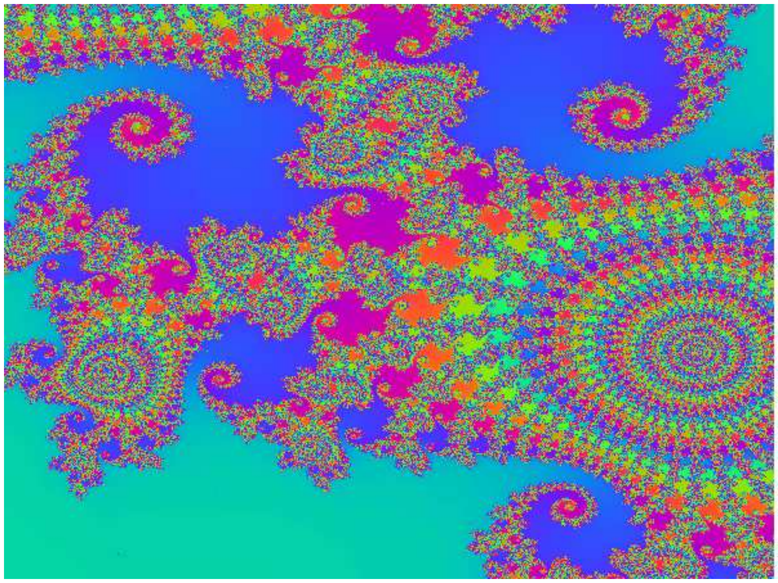
[6]Carlson's Fractal Gallery is at http://sprott.physics.wisc.edu/carlson/.

It has often been said that with sufficiently many monkeys, each with a typewriter (or a computer word processor these days), that they will eventually type all the works of Shakespeare. The problem is that someone has to sort through all the gibberish to find the rare gems. On the other hand, monkeys can and have produced paintings that some people consider to be artistic. Thus it is far less challenging to program a computer to produce visual art than it would be to program it to produce great literature. This is basically what I have done,[7] and my artistic skills surely rival those of a monkey.

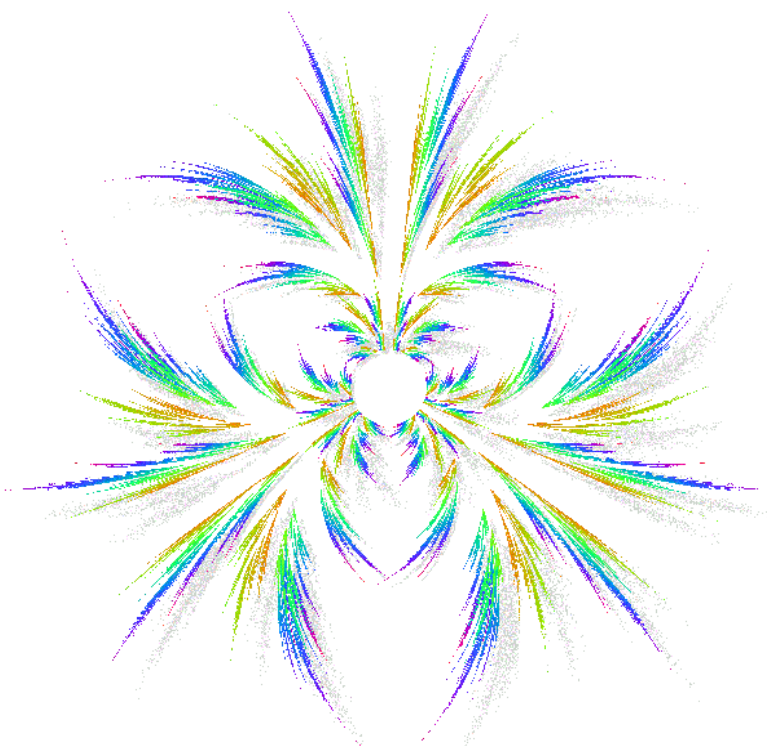
[7] J. C. Sprott, Can a Monkey with a Computer Create Art?, *Nonlinear Dynamics, Psychology, and Life Sciences* **8**, 103–114 (2004).



Some strange attractors from the book *Images of a Complex World*.



Generalized Julia set from the book *Images of a Complex World*.



Iterated function system icon from the book *Images of a Complex World*.

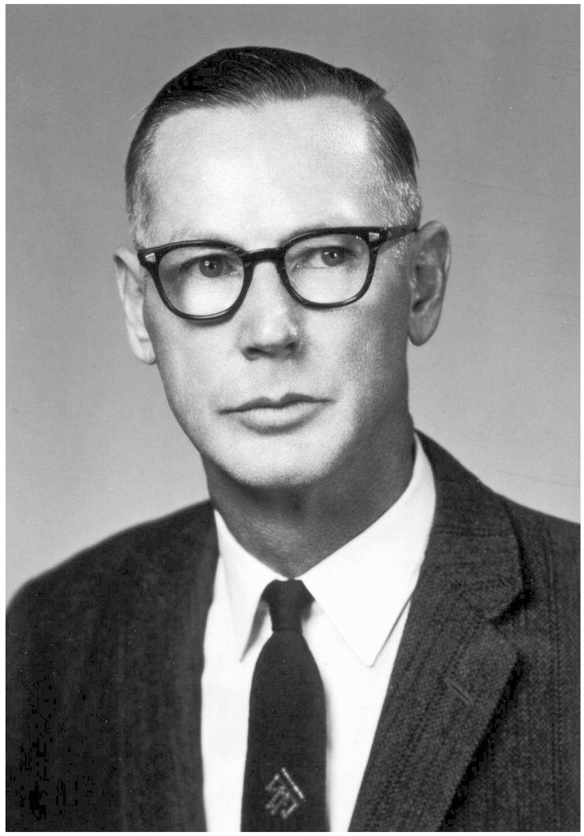
# Chapter 14

# Eulogy to Donald Kerst

> If I have seen farther than others, it is because I have stood on the shoulders of giants. —Sir Isaac Newton
>
> If I have seen less far than other men it is because I have stood behind giants. —Eduardo Specchio

It's hard to overstate the influence that Don Kerst had on my life and career. Although I met him quite by accident, he took me under his wing and more than anyone taught me how to be a scientist. He was my graduate thesis advisor, but he was so much more than that. He was like a father to me, and he believed in me and expected much from me. He convinced the Physics Department to hire me as an assistant professor in 1973, just before such positions became very scarce and competitive, and he turned over the duties of principal investigator of the plasma physics group to me when he retired in 1980. I was the master of ceremonies at his retirement banquet, which was attended by a number of famous scientists.

It was thus a sad day when he was diagnosed with an inoperative malignant brain tumor in 1993. It was especially ironic that he would contract that disease because early in his career he was the first to use the betratron that he had just invented and for which he was most famous to perform high energy X-ray therapy on a patient with a similar tumor. Eventually, most major hospitals had such betatrons, and it was perhaps the most widespread use of a particle accelerator outside of physics. In fact, Don Kerst was the only inventor of an accelerator who never received a Nobel Prize, and many of us thought that was a serious oversight and nominated him for one, although he received many other awards. He once expressed regret to me over not getting a Nobel Prize.



Donald W. Kerst (1911–1993).

When he succumbed to the tumor after several months of deteriorating health, his wife Dorothy asked me say a few words about him at the memorial service that was held in his honor. What follows are my remarks on that occasion:

* * *

Almost thirty years ago, I wandered into a small office in the basement of Sterling Hall and met a tall, distinguished gentleman, whom I had been told was the one to see about jobs in plasma physics. I really wasn't interested in plasma physics, but I was a beginning graduate student in need of financial support, and I had been to all the other groups in the Department without success.

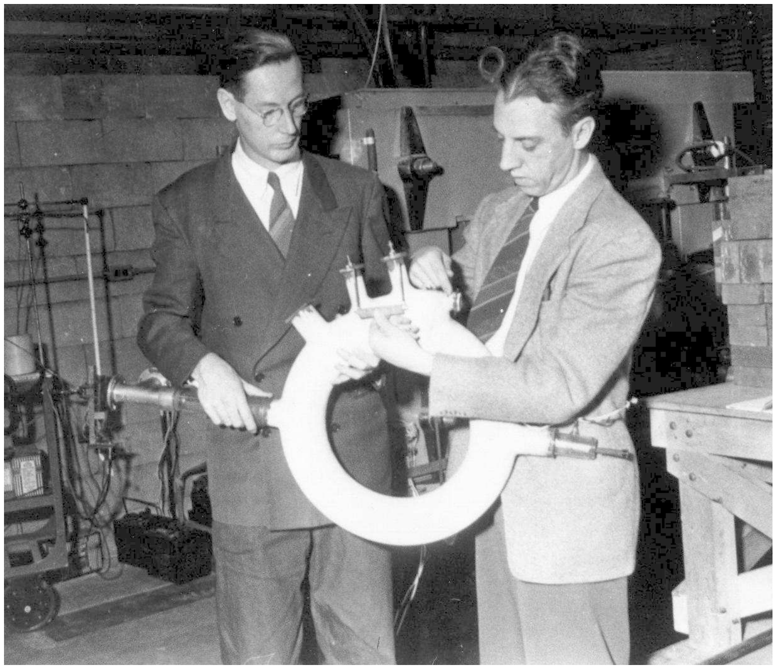

Don Kerst in front of the 400-ton, 300-MeV betatron in about 1950 at the University of Illinois and behind the original 200-pound, 2.3-MeV betatron, completed in 1940 and now on display at the Smithsonian Institution in Washington, DC.

I didn't know anything about this 'Professor Kerst,' but the next five minutes was to launch me on a professional and personal odyssey whose end is yet to come. He listened to my story, and then asked a single question: 'Do you know anything about electronics?' Figuring this was not the time for modesty, I said 'I'm a whiz at electronics,' and he said 'You're hired.'

As time went on, this initial impression of Don Kerst was greatly reinforced. He was compassionate, direct, always helping people perform to the limit of their capabilities, but most of all, he had a driving desire to understand the world around him. To him, physics was not just a profession, but a way of life. He became much more than my thesis advisor. He was more like a father and mentor.

It would be easy for one as accomplished as Don Kerst to intimidate others, but that wasn't his style. He always treated the graduate students as colleagues. He found merit in even the craziest idea. He built others up, not put them down. He expected the best from people, and we worked hard to live up to his expectations.

He was a generous man. He always gave credit to those who worked



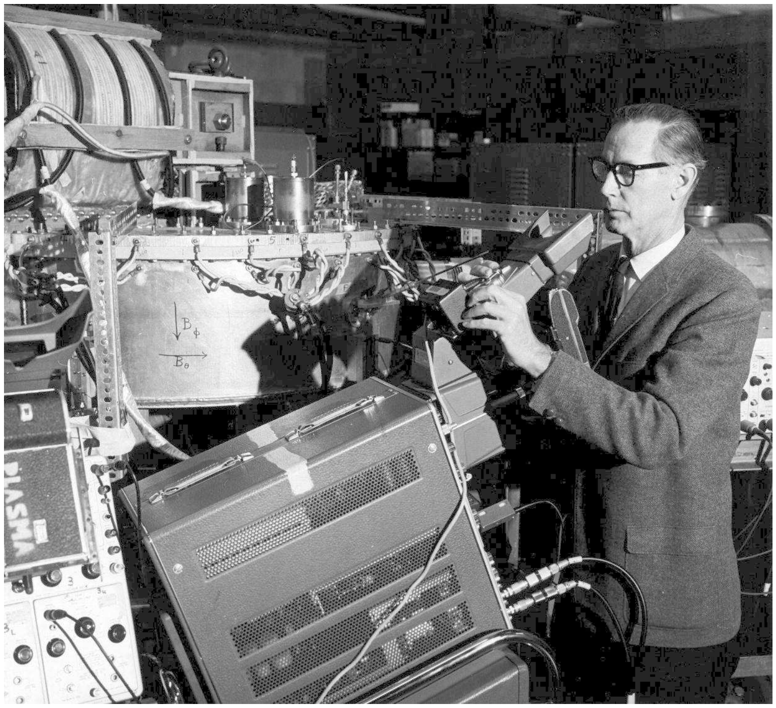
Don Kerst (at left) with the vacuum chamber from one of his early betatrons.

for him. At scientific meetings, he would let us give the talks. He seldom put his name on our papers, even though many of the ideas were his. When important people from other laboratories visited, he would have the graduate students show them around and describe the machines and the research.

And the research that we were doing was exciting. Don had returned to Madison in 1962 with an idea for a new plasma confinement device—the Toroidal Octupole. That device was the one in which plasmas were first tamed, and it revitalized the quest for magnetic fusion energy. Don's leadership and experience helped establish plasma physics as a legitimate scientific discipline.

His love of physics was legendary. Whenever he had a new idea or had figured something out, he had to tell someone. I frequently got phone calls from him early in the morning and listened to what had been on his mind throughout the night. He once had me paged at an airport between flights just to tell me something that he found exciting. And this excitement and thirst for understanding was contagious.

Don also loved the water. Some of my fondest memories of him were of the times we canoed on Lake Mendota or sailed his boat in the Bahamas.



Don Kerst in about 1967 aside the Toroidal Octupole that he invented jointly with Tihiro Ohkawa and on which I performed my PhD thesis research.

He was the consummate captain—confident, commanding, and concerned for detail. But even there, physics was not far from his mind. He would explain how to calculate the hull speed of the boat, or the distance to the horizon, or how to navigate by the stars.

In his later years, Don became interested in ham radio. This was an interest kindled in his childhood by his experiments with spark-gap transmitters. His neighbors would blame him wherever reception was bad on their radios. He also bought a personal computer and spent many—sometimes frustrating—hours trying to learn its intricacies. It was a joy to help him with his radios and computers and to give back a bit of what he so generously gave me.

When Don and Dorothy sold their house in Madison and moved to Florida, he left behind the active research program that he had begun. But his influence continued. Our newest machine includes unusual features that incorporate many of his ideas. He regularly called to inquire about the research. His interest in the program never waned. Nothing made him happier than talking about a new physics problem or result.

This is how I will always remember Don Kerst—friend, mentor, the passionate scientist, and a remarkable human being.

*J. C. Sprott*
*August 1993*

# Chapter 15

# The Diligent Dancer

> You need chaos in your soul to give birth to a dancing star. —
> Friedrich Nietzsche

My parents tried hard to prepare me to be a well rounded adult. They took me to museums, zoos, concerts, and lectures. We took month-long vacations every summer, traveling by car and spending most nights in a different motel. By the time I left for college, I had visited all but two states (Maine and New Hampshire) and most National Parks. They enrolled me in swimming class, made me play on a baseball team, forced me to take clarinet lessons until I finally rebeled, and let me join the Cub Scouts. My dad tried to get me interested in hunting and fishing, and he would take me on his rounds as an office supply salesman, hoping I would learn social skills from him and perhaps join the family business. Of course, they made me attend church, which I hated.

As I got older, they realized that my interests leaned heavily toward science, which they encouraged, although my dad was disappointed that I had no desire to be a medical doctor since he regarded that as the most prestigious profession with the highest social status. When I told him I wanted to be an engineer, he said he knew two engineers, one of whom sold light bulbs and the other climbed telephone poles. Selling light bulbs had no appeal, but climbing telephone poles sounded like fun at my young age. He certainly prejudiced me against engineering, which would have been a fine profession for me, but he could not suppress my scientific interests. My parent's greatest gift was to encourage me to become a ham radio operator at an early age and provide me with radio equipment usually as Christmas and birthday presents. It was the activity I enjoyed most and for which I had the most talent, and it facilitated my career in physics.

I must have been about ten or eleven years old when my parents decided that I should learn to ballroom dance, which was odd because I cannot recall them ever dancing, and it was a bit frowned on by many churches in the South. As best I can recall, one evening a week for several months, they took me to a private girl's school in Memphis where dance instruction was given in the school gymnasium. All the boys would congregate on one side of the gym and the girls on the other. They would demonstrate steps for the waltz, foxtrot, and jitterbug, and then would come the dreaded announcement to choose a partner and practice.

This was unpleasant on many levels, and I didn't display any aptitude for it. It was embarrassing, a bit like the swimming lessons I had to take in the nude. To this day, I still slightly cringe when I hear the Tennessee Waltz, although the waltz is now my favorite dance. However, dancing was a somewhat useful skill for the ROTC Officer's Ball and for the Senior Prom in high school, but I was content not to have occasion to dance for the decade that followed graduation from high school.

In the summer of 1974, I was a new assistant professor seeking to expand my interests beyond the narrow focus on physics that had consumed me in college and graduate school. Walking around the campus, I came across a large group of people, mostly students I assumed, square dancing on the Memorial Union Terrace overlooking Lake Mendota. There was recorded music and a caller, whom I later came to know as Vern Weisensel. The music was upbeat, and the dancers were enthusiastic and seemed highly skilled. I sat on the steps and watched in amazement and perhaps with a bit of envy at the fun they were having.

Just then, an attractive young blonde lady, whom I later learned was a chemistry graduate student, came running up to me and said 'My partner had to leave; you have to dance with me.' I assured her that there was no way I could do that, but she was insistent, and I was soon standing by her side in a square with three other couples. Fortunately, the caller patiently and clearly explained what we were to do and let us practice the pattern before the music started. I discovered it wasn't as hard as it looked, and soon I was having fun despite my awkwardness and numerous mistakes. Between the square dances they would play waltzes, which I bumbled through thanks to that helpful partner and the lessons at the girl's school twenty years earlier.

It turned out that the Student Union sponsored frequent square dances, which I began to attend regularly, and soon I was one of the better dancers. At the square dances, we did waltzes and polkas and some line dances, and so I got reasonably good at that, although it did not come easily, and for several years I had to practice counting the beat so that my footwork would be in time with the music. It turns out that the polka was designated the state dance of Wisconsin in 1993, and there are many polka bands in the area. When I could find a dance partner, we would go to New Glarus where Roger Bright and his band would play polkas every weekend or to the Chalet Saint Moritz in Middleton where an elderly Swiss native named Rudy Burkhalter played polkas and waltzes on his accordion and organ. That was a lively form of dancing quite unlike the slow ballroom style, and I came to enjoy it and developed an energetic, inventive style of dancing that got a lot of compliments especially from the older folks who dominated those dances. I made up for my lack of innate ability and grace with diligent persistence and a bit of flamboyance.

A deep dip of Karen Holden at a ballroom dance in the Memorial Union.

I also discovered there was an international folk dance group that met three nights a week on campus, and I began attending those dances, although I found that style considerably harder since there were hundreds of different dances and relatively little teaching, but it could be done without a partner, and one could learn by following along behind the line and imitating the good dancers without disrupting the dance. In those days, the group did a wide variety of dances from many nations, including line dances, couple dances, and set dances, but it eventually focused on Balkan line dances, most of which seemed rather similar to me, and it became less enjoyable. In the summer, we would dance outdoors, and it was a pleasant way to pass a summer evening, even if I spent rather too much time watching the harder dances rather than attempting to do them. I tried other types of dancing including Scandinavian, Israeli, English, Scottish, and Cajun. Dancing was also teaching me social skills and broadening my circle of acquaintances.

I still had a special affinity for square dancing, but it was hard to endure the teaching that preceded every dance and the repetition of basic steps when there were new dancers present. I was ready for something more advanced. There were about seven square dance clubs in the Madison area at the time, but they mostly consisted of older couples, and their dancing was rather subdued compared to the energetic dances on campus.

A group of us decided to start a square dance club for young singles, which we called the Mad City Squares, and I was in the first class to graduate in 1977 after some thirty weeks of lessons. It was a lively group, but unfortunately it disbanded after about the third year in part because many of the singles got married, and I have only occasionally square danced since then. Our club did sponsor round dance lessons with Milt and Rose Ann Stewart, from which I graduated in 1977, but I have done even less of that since graduating from the class and would be hard pressed to stumble through it now, although I was able to incorporate some of the steps into my ballroom dancing.

About the time the square dances were fading in popularity and availability, a new form of dancing made its appearance in Madison. Dave Titus was a graduate student in Botany who played the fiddle and had learned contra dancing in New England. He organized some dances at the Memorial Union, which he taught, called, and accompanied with his fiddle. They were immediately popular with the students, much as square dancing had been a few years earlier. Those of us who had learned to square dance found it easy since the patterns were similar and everything was taught. It also had the attraction of live music, and one got to dance with many more people in the course of an evening.

For the uninitiated, I should explain that contra dancing is a form of set dancing that had its origin in English country dancing, but was modified when it migrated across the Atlantic. In some ways, it resembles square dancing with a caller and couples dancing with one another and with other couples, but the couples line up in long straight lines facing other couples in small sets of four up and down the line. The couples facing away from the caller are active, and the those facing the caller are inactive, although

Contra dancing with Deb Otto at Folklore Village in 2003.

the steps are usually similar for both. The pattern of steps repeats after 64 counts of the music, with the couples advancing up and down the line each time through the music and thus dancing successively with all the other couples in the line. When a couple reaches the end of the line, they reverse direction, wait out one time through the dance, and then change roles as active and inactive. Once all the dancers have mastered the pattern, the caller stops or minimizes the calling, allowing the dancers to enjoy the music.

The steps are mostly just walking, but it is done to the beat of the music and with a smooth flow. Most of the challenge is in remembering the pattern and trying to be in the right place at the right time and facing in the right direction. The styling is flirtatious with a lot of eye contact, but it is a safe environment with most people there to enjoy the dancing. The dance can even be done outdoors on ice skates, and that was a yearly tradition in Madison until someone became concerned about liability for this potentially hazardous variant.

There are contra dance groups in most large cities, and they are usually welcoming of visiting dancers. I have danced in many places during my travels, even in Europe. In the summer, there are many weekend dance festivals, and some 'dance gypsies' travel from city to city attending festivals almost every weekend. I attended a few of those over the years, but a whole

Contra dancing with Robin Chapman at Grace Church in 2005.

weekend of dancing is a bit more than I need. Since one dances with everyone up and down the line and is expected to switch partners after every dance, it is a form of couple dancing that doesn't require one to come with a partner, and most people are singles attending alone.

However, the constant changing of partners means that it is hard to get well acquainted with anyone, especially for someone shy like me. For many years, I would attend the dance and go home without ever talking seriously to anyone. Then I learned that some people went out for ice cream after the dance, but no one ever invited me, probably because they thought (with some justification) that I wasn't very sociable, and in turn I thought they were cliquish. Eventually, Marjorie Benwitz (Matthews) and Marilee Sandifer (Karamanski) started organizing groups to go out after the dance, and they were careful to make everyone feel included. I began going with them and developing some friendships, many of which have lasted to the present.

Contra dancing on ice skates at Tenney Park in 2001.

In fact, most of my social circle is now centered around the contra dance community, and what limited social skills I have were mostly fostered through contra dancing.

I still contra dance at least once and often twice a week, and I enjoy socializing with my friends and meeting the newcomers who are present at almost every dance. Inexperienced dancers can usually enjoy their first evening of dance, and I try to be especially welcoming to those people and encourage them to return. Being an experienced dancer gives me confidence that I would otherwise lack in social settings, and a number of significant relationships have resulted from those encounters, but that is a subject for another chapter.

# Chapter 16

# Romance and Relationships

> Behind every successful man is a surprised woman. —Maryon Pearson

Thus far I have avoided any detailed discussion of the interpersonal relationships that I have had over the years, but this work would be incomplete without addressing that important aspect of my life. This is a hard chapter to write because it is largely a story of failures for which I accept the prime if not the exclusive responsibility, albeit with a happy ending. It is also an area that is impossible to capture in its entirety, and so I will resort to describing ten especially significant relationships that span a lifetime and that typify the opportunities and disappointments that I have had in this area. My assessment of the dynamics of these relationships may not coincide with theirs or even with reality, but it is how I have retrospectively rationalized what happened. I offer my apologies to the countless other fine women I have dated over the years who did not 'make the cut,' many of whom devoted considerable time and effort to our relationship and shared with me an intense, if sometimes brief, emotional involvement. In this chapter, I have omitted last names to help protect the privacy of those mentioned.

In most ways, I have lived a charmed life. My parents did all the right things in raising me, and they set a good example in their own solid relationship. I never heard them argue or even seriously disagree, and they presented a united front in their discipline of me. They encouraged my scientific interests and applied just the right amount of pressure to excel academically. I was admitted to MIT, my first choice of college, and fell into a program in graduate school led by Don Kerst, the best imaginable scientific mentor. He facilitated my hiring as a professor, which was the ideal job for me. When he retired, I inherited leadership of the well-funded plasma group that he had established. I effortlessly received tenure, and when I tired of administration, Stewart Prager was at hand to eagerly and effectively take over the project. George Rowlands entered my life at just the right time to set me off in a new and exciting research direction that consumes me even now. *The Wonders of Physics* was an instant and easy success because of the role model I had in Bassam Shakhashiri. I only wish that I had been more lucky and successful in my personal relationships, but I was tireless and eternally optimistic—and ultimately rewarded.

## The Tomboy

As part of my upbringing, my mother encouraged me to have a girlfriend at a much earlier age than most of the other boys. She noticed my interest in Mickey when we were perhaps eight or nine years old, and she would chauffeur us on various 'dates.' We would go to movies and social events together. Mickey was a bit of a tomboy and we would hike, ride bikes, and climb trees together. I once recall her joining several of us crawling through the storm sewers, which greatly impressed me. I liked having a special friend, although I was too young to feel any deep emotional involvement.

Mickey was a bit more advanced in that area than was I, and she taught me to kiss, once encouraging me to see how long we could prolong a kiss while on a hayride. I lost interest after about fifteen minutes. We might have gotten into serious trouble if I had been more interested in girls and continued our relationship into our teenage years, but my interests were turning to ham radio, and I lost track of Mickey by the time I began to take a more serious interest in girls. I think she might have attended a different high school, and we lived far enough apart that we rarely saw one another. I had no contact or information about her after leaving for college, but I still remember her fondly.

## The Athlete

By the time I was a high school senior, I was interested in girls. My best male friend, Quent Cassen, had left for college at Vanderbilt, and I was developing some self-confidence in part through my role as a major in ROTC. Some of the other boys had girlfriends or at least had someone with whom to attend after-school events. Suzanne was one of the sponsors who marched with us in parades. I knew that she was interested in sports, and so it was natural to invite her to attend football and other sports events with me. She played for a girls' basketball and softball team, and I would watch her play, and we would go out for hamburgers and soft drinks after her games. By that time I had my driver's license, and my parents generously let me use the family car. We would usually go out every weekend, sometimes on amateur radio transmitter hunts, and we both had a midnight curfew. We would sometimes play tennis together, and her father once took us to an all-night bowling alley from which we returned at 3 am to the chagrin of my mother. Suzanne was voted the most athletic girl in our high school Hall of Fame.

Me with Suzanne at the ROTC officer's ball in the spring of 1960.

On one of our early dates, we decided to 'go steady,' which meant that we exchanged class rings and agreed to only date one another. That was an era in which 'nice girls' saved themselves for marriage, and nice boys respected that, which we did. There was an unspoken limit to how far we would go when we parked out by the airport watching the planes land at the end of our dates, although the kissing skills that I learned from Mickey years earlier came in handy.

Our relationship mostly ended when I left for college, although we corresponded by mail, and she flew to Boston to visit me during Thanksgiving of my freshman year, and we had a few dates the following summer. After that we lost touch for the next two decades during which time we were both married and divorced, received our PhDs, and became professors—she a professor of physical education at West Texas A&M University. Eventually we began exchanging Christmas and birthday cards. Sometime in the late 1980s she visited me in Madison, but we decided that whatever spark had earlier existed was then extinguished, and we lost touch again. I was sad to learn that she died on August 14, 2002 at the young age of sixty.

## The Nurse

College did not leave much time or opportunity for dating since MIT at the time was overwhelmingly male and I was in a period of serious religiosity. However, I did encounter young women at the College-Career Club at Tremont Temple Baptist Church in Boston, and in my junior year, I invited a nurse Mary Ann from Children's Hospital in Boston to attend a church dinner with me. We began dating and corresponded during the following summer while I was playing missionary in Brazil. The relationship heated up during my senior year, and we spent much time together during the summer after I graduated. I was applying for graduate schools during that year, and she was applying to schools for an undergraduate nursing degree. The only school to which we both applied was the University of Wisconsin, and it turned out to be the best choice for us both.

We drove together from Boston to Madison in August of 1964 and moved into Witte Hall, a dormitory with separate wings for men and women. The dormitory had a strict curfew for women, and it was hard to say goodbye to her at 10 pm every night. That was before it was acceptable for unmarried couples to live together, especially ones who professed Christianity. Most of the other graduate students in my lab were married, and so there was social as well as hormonal pressure to get married. During Christmas of that year we visited my parents in Memphis, and I surprised Mary Ann with an

Mary Ann, the nurse to whom I was married for eight years, 1965–1973.

engagement ring as a Christmas present. We were married on June 5, 1965 in a simple ceremony at Faith Baptist Church in Monona, Wisconsin, attended by our parents and a few other relatives and friends we had made during the year in Madison.

Unfortunately, things did not go well from the beginning. At age twenty-two, neither of us was very mature, and we both had unrealistic expectations of married life, especially having not previously lived together nor with anyone of the opposite sex. This was compounded by the fact that I was disavowing my religious beliefs while she was embracing hers more firmly, and she blamed our problems on my falling away from the faith. Without compromise or apology, I gave priority to my physics studies over religion and my marriage. She continued to be the good wife even as we inevitably drifted apart. By the time we moved to Oak Ridge in 1970, we had few common interests and were staying together only because we both took seriously the vows we made 'until death makes us part.' Fortunately, we were wise enough not to have children since it was obvious that the marriage was not conducive to parenthood and I didn't want anything to interfere with my career.

For Christmas of 1971, she returned to Maine to visit her parents, while I flew to Memphis with my dog Ralph to be with my parents. She remained in Maine for the next few months during which time I received the offer to return to Madison, and she moved back to Oak Ridge only after I had left for Madison in June. We never lived together again, and a year later I filed for divorce after she threatened to garnish my wages at the urging of her father. The divorce was uncontested, and I paid her $12,000 and had no further contact with her except to note that her (my) name remained in the Oak Ridge phone book for the next few years.

## The Student

When I returned to Madison in June of 1971, separated from my wife but still legally married, I felt anticipation but apprehension over starting a new phase of life. I resumed playing tennis after a decade of athletic inactivity, but I did not have a regular partner. After work, I would go to the tennis courts on campus where there was a backboard against which people practiced hitting the ball. I would do the same and offer to play with others who were there alone. Soon I spotted Melanie, an attractive, mature, eighteen-year-old with long curly dark hair, and I watched her practice for a while before offering the suggestion to 'put more of your body into the swing.' We began meeting at the court every day to play, and I soon invited her to my apartment for a hamburger. It was not long before we fell in love despite the ten-year age difference and my marital status, which did not overly concern her. Her parents, with whom she still lived, treated me like a son and encouraged our relationship. My parents were befuddled when we flew to Memphis to visit them the next Christmas while I was still married, but they liked her and were glad I had brought her to meet them. She helped me update my wardrobe and encouraged me to grow my hair and sideburns to a more fashionable length. I looked a bit like Carl Sagan in my turtleneck sweater and long hair.

Melanie was a French major but was switching to physical therapy, for which she had to take a physics course. She would walk over to my apartment every day after class, and we would have dinner, and I would tutor her in physics. About 2 am every morning, her mother would call and tell her it was time to come home, at which point I would drive her home. That continued for a year, during which time we did many things together, primarily

Melanie and me in 1973.

swimming, skiing, and flying—and I got divorced. The next year, she rented an apartment near campus, which she rarely visited, and we lived together in my apartment. Her parents pretended not to notice and continued to treat me as a son (in-law). It was one of the best years of my life. She wanted to get married, but I thought she was too young and inexperienced, and I was cautious because of my recent failed marriage.

In June her lease ran out, and she moved back in with her parents for the summer of 1974. That caused us both considerable stress and uncertainty over our future. I spent a week at a physics conference in Texas, and when I returned, she had been swept off her feet by a handsome, blonde muscle-man who worked for her father in the funeral business and looked like he was right off the beach in California. That was the first time I had been seriously hurt by losing someone about whom I cared deeply. Their relationship lasted for a year and ended badly when he was caught stealing from her father. Then she wanted to get back together, and I tried that, but too much time had passed, and she was then living in Minneapolis and subsequently in Milwaukee. I had begun to date others and to enjoy and exploit the bachelor life. She eventually married and had two children, and she still occasionally stops by my house with her husband Fred when they are in Madison. She is the woman friend that I have known the longest, and she will always be my first real love.

## The Lab Rat

Reeling from the loss of Melanie, I began searching for someone to replace her. By that time I was meeting many women at dances, and my status as a young bachelor assistant professor facilitated countless opportunities. Only my inherent shyness and inexperience with dating, along with the long hours I was spending in the lab, kept me in check. I began having relationships, but none could replace Melanie, and I began a period of casual dating. That was an era after the pill but before the fear of STDs. For many people, sex was the expected culmination of a date, and I adapted quickly.

One of the people I was dating casually was Carolyn, a disheveled first-year graduate student in molecular biology, whom I had met at a folk dance. We had wonderful intellectual discussions, but I was not physically attracted to her. I helped her buy some better clothes and sent her to the doctor to have her ears pierced, much as Melanie had transformed me a few years earlier. We continued a non-exclusive relationship for about a year, at which time we went sailing in the Bahamas. We flew there to meet Don Kerst and his wife in a rented plane with another physics professor, Keith Symon, and his son Jim. It was on that trip that I fell in love with her, seeing her enthusiasm for sailing and intelligence about navigation. Others on the boat slept while we piloted and navigated across the Gulf Stream back to Florida throughout a cloudless, star-filled night. It was a romantic experience.

At the conclusion of that trip, she moved in with me, got her amateur radio license, took square dance lessons with me, and we shared the intellectual life of two scientific researchers. The next two years were good, and she wanted to get married, but I felt that she would be sacrificing her career by staying with me in Madison. It was stressful watching her apply for postdoctoral positions around the country, and we broke up shortly before she got her PhD. During her brief final months in Madison, she met an underem-

Carolyn and me sailing in the Bahamas in the late 1970s.

ployed guy who moved with her to the San Francisco Bay area where she took a job with a small startup-up genetics company whose name 'Escagenetics' she had the honor of choosing. I was not overly worried since I had fallen in love twice in the previous five years, and I was having no trouble meeting women. However, a whole decade passed during which I had far too many relationships, but none to compare with Carolyn. I regretted not marrying her when I had the chance, and my only consolation was that I had done what I thought was best for her.

After a decade of being out of touch, the phone rang one afternoon. It was Carolyn. She was in Madison for a conference and wanted to know if I would like to have dinner with her, which I eagerly accepted. It was like we had never parted. I remembered all the reasons I liked her so much. I asked her if she had any interest in returning to Madison and a life in academia. She said that she would if she could get married. Without a moment's hesitation, I said, 'if you return to Madison, I'll marry you.' However, we were both living with other people in unhappy relationships, about which I will say more shortly.

We spent the weekend canoeing on the Kickapoo River, after which she returned to California, informed her long-time boyfriend that she was getting married, submitted her resignation, and put her house up for sale. I informed the person I was living with, who fortunately had retained an apartment nearby for just such an eventuality. Carolyn shipped her bicycle and many of her clothes to Madison and returned a month later to use her six weeks accumulated vacation, after which she returned to California to finish her work there and sell her house. She promised to return to Madison for good in about a month.

While back in California, a man who worked with her discovered that she had separated from her boyfriend and invited her to go sailing with him in the San Francisco Bay. She asked me whether she should do it. I told her that he probably had more than sailing in mind but that she was free to do what she wanted. I called her late that evening and got her answering machine. She returned the call the next morning, and sheepishly said that I was right about what he wanted. He pursued her relentlessly for the next few days, even having the operator break in on our phone call. Perhaps I should have fought harder, but he had the advantage of proximity, and they were married about a year later. She said she had never before been so happy. I had to ship back her bicycle and clothes, and we never saw or spoke to one another again.

Almost two decades later I discovered that on August 7, 2008 she had died of amyotrophic lateral sclerosis (ALS), often referred to as 'Lou Gehrig's Disease,' at the young age of fifty-five. I cannot help but feel that I dodged a bullet since it would have been incredibly hard to watch the slow, painful death of someone for whom I cared so much. I'm only glad that she had a loving husband to comfort her in her final days.

## The Professor

The decade after Carolyn first left for California is a bit of a blur. I assumed I would soon find another love, and I dated numerous women for periods of a few days to a few years in a long succession of turbulent relationships, some involving intense emotions. That came to an end when I met Cindy. She had placed an ad in the personals saying that she was a young assistant professor looking for an educated man. We met one Saturday morning and went to the Farmer's Market. She was attractive and seemed delighted to have met another single professor, and we sat on the grass and talked for about an hour. She was busy that afternoon and evening, but I invited her over to my house the next day. She came and stayed for the next three years.

Unfortunately, we had nothing in common other than being university professors. Her field was quite remote from mine. She tried dancing, but it didn't come naturally, and dancing with her was not enjoyable. I quit dancing for those three years, and I missed it greatly. I was an avid bicyclist, and I bought her a bike, but she biked so slowly and cautiously that it was unpleasant biking with her. She would drive her oversized car two blocks to the grocery store. She enjoyed spending the day sitting around talking to relatives and friends, which was quite unbearable for me. Despite her being ten years my junior, I felt that I was quickly growing old with her.

However, it was a productive time scientifically. I had just switched my research area from plasma to chaos. I wrote several commercial software packages and a book on *Numerical Recipes*, and I was beginning work on the *Strange Attractors* book. But I was bored in my personal life. It scared me that my relationship with Cindy was much like my marriage many years earlier, which was also a scientifically productive time, but otherwise unfulfilling. Yet I remained with her because she was kind and took good care of me, and I didn't want to resume dating. Our relationship began a downward spiral when her relatively young mother took ill and shortly died of cancer. I was not very supportive in part because I had no experience dealing with death, and she never quite forgave me for that. Thus when I got that phone call from Carolyn asking me to join her for dinner, I was primed to move on to someone with whom I was more compatible.

## The Psychologist

After the brief reappearance and disappearance of Carolyn in my life, I became disillusioned with relationships. I quickly met Margaret, a kind, attractive divorcee who was an excellent dancer. In fact she had a bachelor's degree in dancing, and she competed in and taught Scottish highland dancing. We spent a couple of years seeing one another every Wednesday and every other weekend, but I was not over the trauma of losing Carolyn for a second time, and she was looking for a father for her two rebellious teenage daughters. She eventually left me when she finally accepted that I had no intention of being their father, and she quickly found someone else to marry.

Soon thereafter, I spotted an ad in the personals by an 'academic in her third decade looking for a mate.' I answered her ad and found that Debbie was a psychology professor at a university in Whitewater, Wisconsin, about an hour away, recently arrived in Wisconsin from Vancouver where she had attended graduate school, and that she knew of me from having seen my *Strange Attractors* book in a Chicago bookstore. We began a relationship that was hindered by the distance between us, but she had one characteristic that impressed me and that only Carolyn had previously possessed. She was intensely interested in my research, which at that time included fractals and aesthetics. We became research collaborators, with her designing experiments and providing student subjects and me writing software. She was also a bit of a computer nerd, and we constantly debated whether the PC or the Macintosh was the better platform. She was a good bike rider and a passable dancer.

Unfortunately, she did not consider our relationship an exclusive one, and I had a hard time dealing with that and eventually had to end it. She subsequently married, moved to New Jersey, and divorced, but we have remained friends throughout and occasionally discuss resuming our scientific collaboration.

## The Polka Dancer

I dated a number of others over the next few years, but I could not find anyone special until one day in 1998 I saw Marsha at the Farmer's Market. I recognized her from contra dancing but had never spoken with her. She mentioned that there was an all-day polka dance at a nearby park celebrating the 150$^{th}$ anniversary of Wisconsin's statehood (the polka is the official dance of Wisconsin) and that I should stop by later, which I did. She was the best polka dancer I had encountered, and she had great stamina. Despite the intense heat, we danced steadily under a tent for the next six hours. Afterwards, we went out to dinner and then back to my house for the evening and resumed dancing the next day. For the next year or two, we danced at every opportunity and had great fun, and we went on a number of other outings including week-long trips to Huatulco, Mexico and to Banff National Park in the Canadian Rockies.

The trip to Huatulco was noteworthy because I did not know where I

Me with Marsha at Banff National Park in September of 2000.

was going until I was on the airplane. Marsha had said she wanted to take a vacation, and I agreed to join her. She asked if I cared where we went, and I said that it really didn't matter but someplace warm would be nice since it was toward the end of the long Wisconsin winter. Some days later, she said she had decided where she wanted to go, and she asked if I wanted to know. With a mixture of romantic intrigue and callous indifference—probably more of the latter than the former—I said I didn't need to know, only what to pack, and she said to pack clothes for a warm climate and swimming and to bring my passport. I figured it was somewhere in the Caribbean or South Pacific. On the appointed day, we drove to O'Hare, parked in the long-term lot, and got on the shuttle bus to the terminal. Someone on the bus asked me where I was going, and everyone laughed when I said that I had no idea, thinking I must be a bit of a clown. Marsha volunteered that we were going to Huatulco, which was no help since I had never heard of it. They said it was a lovely spot and that we would have a good time there. Arriving at the gate didn't solve the mystery either because the sign said 'Huatulco' with no indication of the country or part of the world. At about the time the plane took off, I surmised that it must be in Mexico because of the Spanish-sounding name and the fact that her brother and Mexican wife lived in Mexico City where he taught school. It was a pleasant but otherwise uneventful trip in a brand new beachfront hotel on the Pacific Ocean at the far southern tip of Mexico.

Marsha lived on a farm some distance from Madison, and so it was difficult to see one another except on the weekends. She wanted a dating relationship and didn't seem interested in taking it further. She also wanted me to initiate more, which has always been difficult for me. Finally she grew tired of planning all our dates and decided to wait for me to initiate, which I stubbornly refused to do. We rarely saw one another after that, which didn't greatly bother me since I wanted a live-in partner, although I missed dancing with her. Eventually, I found someone else as did she, and last I heard, she was living in Seattle with someone she had known from much earlier. We occasionally exchange terse emails.

## The Swiss Miss

For half a year after Marsha was waiting for me to initiate, not much was happening in my life until one evening when two young, attractive, vivacious women appeared at the contra dance. They were officemates in the Department of Forest Ecology and Management on campus. Emilie was a graduate student from Oregon, and Janine was a postdoc from Switzerland. I asked Janine about her research, which was a fascinating topic involving the spatial distribution of forests in Southern Wisconsin in the early 1800s before it was settled. I suggested we have dinner to discuss it further, which she eagerly accepted. At dinner, I realized that her forest problem could be easily modeled using a cellular automaton, which I had been studying for another purpose. Shortly thereafter, she sent me an email saying that although she would be returning to Switzerland in about four months, she would like to spend her remaining time with me enjoying the summer and coauthoring some papers, which I eagerly accepted.

We began seeing each other every day, working on research, and sharing many activities. Despite our best intentions, the twenty-six year age difference, and the fact that she would return to Switzerland shortly, we fell much in love. After a whirlwind summer, it was time for her to return to Switzerland and to the job she had waiting there. It was an emotional parting, but we had mentally prepared for never seeing one another again. The next day, I got a phone call from her in Switzerland saying how distressed she was, and I realized that my teaching schedule would allow me to spend three weeks visiting her about a month later, which I did. It was wonderful being together again, with her showing me all the best spots in her native land, which I found beautiful and enchanting.

Janine and me at the Matterhorn in April of 2002.

We decided that we wanted to be together and that she would look for a job in Madison. She had no interest in getting married but was uncertain about having children. Over the next year, she visited me in Madison three times for periods of three months, three weeks, and one month, and I visited her twice more for periods of one month and six weeks. I wrote major parts of my *Chaos and Time-Series Analysis* book in Switzerland. We coauthored two papers and traveled around the US and Europe together giving talks about our joint and separate research.

However, she was unable to find a job in her field in Madison, and there was no position for me in Switzerland comparable to the one I had. Then in December of 2002, she got an attractive job offer teaching at the University of Zurich, the largest and most prestigious university in Switzerland. It was an opportunity she could not refuse, and she thought it was time for us to part. I was devastated, and I considered quitting my job and moving to Switzerland, but we both knew that I would not be happy with that decision. She was quite firm in her belief that parting was for the best. We exchanged long emails for the next several months, but that was too painful, and I told her that I needed to sever communications and take time to recover, which took over a year. I have not seen her since, and we have only exchanged two brief emails, but I gather that she is doing well in her life and career, and that gives me some consolation.

## Marriage

The year after Janine left me was a blur. I was more depressed than I had ever been, despite numerous fine women who took compassion on me like a wounded puppy and whose kindness and caring I did not adequately appreciate or reciprocate. Eventually, I began to feel better, but I was cynical about relationships, feeling that nothing is permanent and that one just has to enjoy people for what they have to offer and not ask for more than they can provide. I was settling into a life of permanent bachelorhood, with a number of specialized partners who each had different qualities to offer.

After several years of an active and mostly satisfying social life, I was married in 2010. My wife has requested that her name and the details of how that came about be kept private. She has consented to my reporting that she does all the cooking no matter how tired she is and takes good care of the house despite my occasional untidiness (I often leave the bed unmade) and that we both snore loudly, which has caused some misunderstandings. Only time will tell how this relationship will work, but we have been together over four years, still get along reasonably well, and are hopeful that our years of searching for mates are finally behind us.

# Chapter 17

# Asperger's Syndrome

> The statistics on sanity are that one out of every four Americans is suffering from some form of mental illness. Think of your three best friends. If they're okay, then it's you. —Rita Mae Brown

For most of my life I have felt socially awkward. I have usually attributed it to shyness, a paucity of social experience perhaps because of my focus on science, or just a bit of quirkiness. One obvious manifestation is the difficulty I have had maintaining long-term romantic relationships, but I have also had few close friends over the course of my life, and I am sufficiently uncomfortable at social gatherings that I often avoid them except with individuals or small groups of people that I know well. I have trouble remembering names and faces, and seldom can I visualize the face of someone I know well. I find it difficult to maintain eye contact and to carry on a prolonged casual conversation. I also have a tendency to annoy or offend people unintentionally by saying things to them without realizing how my words are perceived. The closer I am to the person, the more likely I am to speak without thinking, which contributed to some of my failed relationships.

One day, while visiting with Susan Kiedrowski, she pulled out a sheath of papers and began asking me a series of odd questions,[1] recording the extent of my agreement or disagreement to each: 'Other people frequently tell me that what I've said is impolite, even though I think it is polite.' 'I would rather go to a library than a party.' 'I enjoy social chitchat.' 'I don't particularly enjoy reading fiction.' 'I frequently find that I don't know how to keep a

[1] See http://www.wired.com/wired/archive/9.12/aqtest.html for the Autism-Spectrum Quotient (AQ) Test.

conversation going.' 'I find it easy to work out what someone is thinking or feeling just by looking at their face.' 'New situations make me anxious.'

After fifty such questions, she gave me a score of 31 and told me that the average score of a control group was 16.4 and that eighty percent of those diagnosed with autism or a related disorder scored 32 or higher. She said I had many of the characteristics of Asperger's Syndrome, about which I knew almost nothing, and she referred me to a number of websites with more explanation and detail.

The more I read and learned about it, the more I felt that her diagnosis was probably correct. Asperger's is a mild form of autism that often affects gifted individuals, especially in the sciences, and it is a condition for which there is no real treatment or cure, although it can be managed. I found that I was in good company since others suspected of having a degree of the same syndrome include Albert Einstein, Abraham Lincoln, Bill Gates, and Isaac Asimov.[2]

A short explanation has been provided by Jerod Poore:

'Asperger's Syndrome is a form of high-functioning autism, first identified in 1944 by Dr. Hans Asperger in Vienna and later refined in 1981 by UK psychologist Lorna Wing. Asperger's is part of the autistic spectrum, and is in itself a spectrum syndrome. As such the effects range from severe to mild, although in autistic terms severe Asperger's is relatively benign. You may not fit into society very well, but you can still take care of your basic needs, more or less. Mild Asperger's is just seen as eccentric, except when those rages strike, then you're a first-class jerk with no self-control. Anyway, here are some of the characteristics found in Asperger's [*to which I have added commentary in italics on the extent to which they apply to me*]:'

- We just can't accept criticism or correction.

  *I do become defensive when criticized or corrected, preferring to justify my words and actions rather than admitting that I am wrong.*

- Yet when we offer criticism it invariably comes across as harsh and pedantic.

  *I have been told that I'm not very tactful and that I don't nuance my words or consider how they make the other person feel. I have often*

[2]See http://www.disabled-world.com/artman/publish/article_2086.shtml for explanations and many other examples.

*offended or hurt others with my thoughtless words. Often I have no idea what I did or said that was offensive. I do better in writing and with people whose native language is not English, at least until they know me well, since they are inclined to assume they misinterpreted my unintended insults.*

- We just don't get the unwritten social rules, subtext and the unspoken communication such as stance, posture and facial expressions.

  *I am often clueless about how someone feels unless they provide an explicit verbal explanation.*

- We often fail to distinguish between private and public personal care habits: e.g. nose picking, teeth picking, ear canal cleaning.

  *I might have been guilty of this on occasion, but I think this applies more to children with Asperger's since intelligent adults can usually learn to avoid such inappropriate behaviors.*

- We often have a nave trust in others.

  *I do tend to give people the benefit of the doubt, but my scientific instincts lead me to be skeptical of things that people say without supporting evidence, and I like to argue the other side of issues, just to ensure balance and objectivity as I feel scientists should do.*

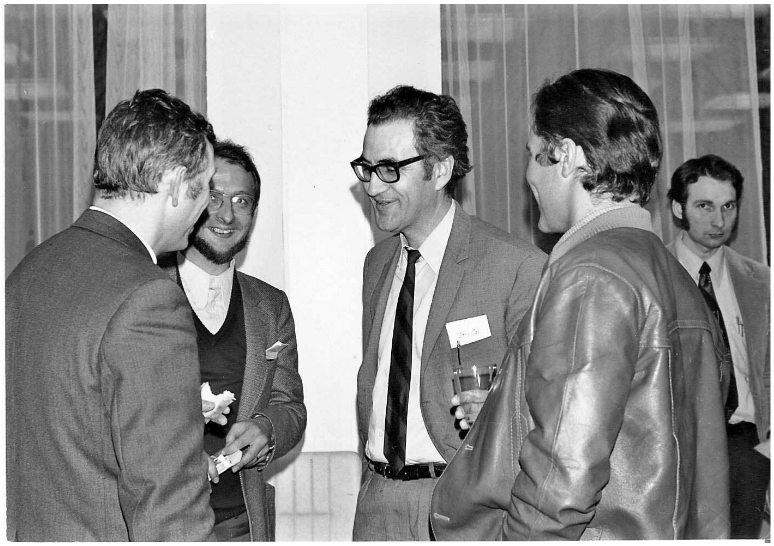
- We're painfully shy.

  *This has been a problem throughout my life especially in situations where I feel insecure, but acquiring strong academic credentials and developing skills in dancing have helped alleviate the problem in settings where I feel competent and superior to those around me.*

- We have constant anxiety about performance and acceptance, despite frequent recognition and commendation.

  *I do worry about offending people or appearing foolish, although I have always been comfortable lecturing even to large audiences, perhaps because I can feel superior in such settings. I have received a good bit of recognition and commendation.*

- We're brutally honest.



This unposed photo of me at the far right during an international scientific conference in the mid 1970s well illustrates the discomfort I often feel in social settings.

*Don't ask me how I like something about you if you are looking for reassurance. The instinct to give an honest rather than a tactful answer is so strong that I frequently cannot help myself, although in retrospect, I often realize that I should have answered differently.*

- We're blunt in emotional expression.

  *If you tell me that your mother just died, I'm more likely to say 'don't worry; you'll eventually feel better' than to say 'oh, you must feel awful.'*

- We have the infamous flat affect.

  *The 'flat affect' refers to the tendency to show little emotion, especially in facial expression and body language. This is a symptom of depression and is more noticeable in children with autism than with adults who are often expected to suppress extreme emotions. I may have a degree of this since I tend to respond philosophically and rationally to things that happen more than emotionally. Rather than being distraught over life's calamities, I immediately begin considering implications and solutions.*

- We have either no apparent sense of humor or a bizarre sense of humor that stems from complex references that would be far too annoying to explain.

*I have sometimes failed to see the humor in things that others find amusing, and I occasionally don't understand jokes, but for the most part I think my sense of humor in intact.*

- We have great difficulty with reciprocal displays of pleasantries, greetings and small talk.

  *I often find small talk painfully difficult and tedious.*

- We have a lot of problems expressing empathy, such as condolence or congratulations.

  *Congratulations are easier than condolences, and I can hardly relate to what it means to express empathy.*

- We can't obscure real feelings, moods, and reactions. It's either nothing or overwhelming, there is no emotional middle ground.

  *For the most part, my emotions are well under control, but I can get somber, sometimes for days on end.*

- We will abruptly and strongly express our likes and dislikes.

  *Usually I try not to let things bother me, but occasionally something triggers a strong, perhaps unreasonable perverse reaction.*

- In an attempt to deal with all that small talk, empathy, jokes and the like we will adopt rigid adherence to rules and social conventions per Miss Manners.

  *I'll just smile and nod my head and keep quiet if a conversation seems inane, tedious, or uncomfortable.*

- We'll often fixate on and excessively talk about one, or a limited number of interests.

  *My interests and expertise are definitely narrow, and I can talk at length on a subject that excites me, but I tend to withdraw from discussions of topics about which I know little, or I look for ways to relate what is being said to something that I find interesting.*

- We have a flash temper & occasional tantrums.

  *I usually have a fairly even temper, but on rare occasions I become exasperated and angry when I think someone, especially someone with whom I am close, is being stubborn or illogical.*

- We have incredible difficulty forming friendships and intimate relationships. Yet being desperate for emotional intimacy we have problems in distinguishing between acquaintance and friendship. We suffer from 'one real friend at a time' syndrome, but can't really tell if the other person is reciprocating, and don't understand why they don't feel the same way.

  *Through my early adult life, I had no close friends except for my many sequential significant others. This made it difficult in the frequent but brief lonely periods between relationships. At about age fifty, I began to develop some friendships, many through the contra dance community, that have survived and coexisted with my romantic relationships, and the current situation feels considerably more healthy than in the past. In many cases I have no idea whether those I consider as friends think of me in the same way or as mere acquaintances. I have often said, to the amusement of some of my friends, that I find it much easier to have a romance than a friendship. Certainly my few friendships have now outlasted the longest of my many romances.*

- We're socially isolated and often have an intense concern for privacy, despite not being able to understand 'personal space' all that well.

  *This was more true earlier in my life than it is now, but even now, few people with whom I interact professionally know anything about my private life, even whether I'm married or not.*

- We have limited clothing preference and will wear the same clothes for days at a time. We'll cut off all the tags on the inside of clothes and cannot wear certain fabrics.

  *I do tend to wear the same style of clothes all the time, although I change clothes every day, and I have never removed tags from clothes or shunned particular fabrics.*

- Which goes along with various sensory sensitivities. Certain sensations, such as particular sounds, colors, tastes, smells, will just set us off.

*I am not aware of having this characteristic.*

- We are the *uberklutzen*. We are clumsy. We have problems with balance and judging distances, height and depth. We have gross or fine motor coordination problems. And we frequently have an unusual gait, stance, and/or posture.

  *I don't think of myself this way, but the evidence is that I'm not very good at most sports, and so perhaps there is an element of physical clumsiness, but it is not extreme or problematic.*

- We have great difficulty in recognizing others' faces (prosopagnosia) and the emotional expressions that play across your faces.

  *Some people never forget a face; I rarely remember one. I often get people confused with one another, and I cannot usually form a mental image of someone's face, even someone I know well. If asked what color or length hair someone has, or whether they have a beard or wear glasses, I usually have no idea. If I watch a movie with multiple similar characters, I get them confused, and this often makes it difficult to follow the plot. At times, I will encounter someone I know but will have no idea who they are or from where I know them. Sometimes I have absolutely no recognition of someone I once knew very well if I haven't seen them for a few years, and this has caused occasional embarrassment and has sometimes led me to avoid situations in which it might occur.*

- We have difficulty initiating or maintaining eye contact.

  *I find it intensely uncomfortable to make more than a fleeting eye contact with someone, although in contra dancing, the style is to make eye contact while swinging with one's partner or neighbor, and I am able to do that perhaps by looking 'through' rather than 'at' the person.*

- During periods of stress and frustration we'll raise our voices all right. But it won't be yelling. Call it 'yelling' and you'll hear yelling. Then you'll know the difference.

  *I have done this, but rarely, and only when extremely frustrated.*

- We have some strong and unusual food preferences and aversions, and equally unusual and rigid eating behaviors.

*I've taught myself to eat most things, although with different degrees of pleasure and tolerance. I would be reasonably content to eat the same few favorites every day for my whole life, and I have nearly done so for breakfast, which almost always consists of cereal with strawberries and a doughnut. I realize that is probably not healthy, and I'm glad to now be married to a food scientist and excellent cook who serves a tasty and nutritious variety of meals.*

- Our personal hygiene is sometimes odd or leaves much to be desired.

  *I believe I have learned to be properly and adequately hygienic, at least in public.*

- We will just shutdown in response to conflicting demands or high stress.

  *Fortunately, I have organized and lived my life so as to be relatively free of demands and stress, and so this has rarely been a problem. I can recall occasional instances of shutdown in response to conflicting demands, and so with a different job or a different family, I can imagine this could be an issue.*

- We have a low understanding of the reciprocal rules of conversation. From person-to-person, day-to-day or conversation-to-conversation you'll find us interrupting and dominating, or not participating at all. We often have difficulty with shifting topics and will keep trying to steer things back on subject. It's just painful that we don't know how or when to start or stop a conversation.

  *I can relate to this difficulty, although it sounds slightly overstated as it applies to me.*

- We take literalism to new frontiers.

  *I am guilty of this. If you ask me a question, choose your words carefully, and forgive me if my answer seems to be to a different question than the one you thought you asked. I'm not (usually) trying to be funny or perverse, just accurate and precise.*

- Our rage, tantrum, shutdown, and self-isolating reactions may appear 'out of nowhere' but they really do have meaningful triggers. First there's a lot of self-anger, anger towards others and the world in general, and basic resentment. But where normal people are picking up non-verbal cues, we're picking up precise meanings and shades of meanings of the words that were chosen and how they relate to what may have been said months or years ago. Some clever turn of phrase may carry a lot of personal meaning that you just couldn't possibly understand.

*I don't believe I have self-anger or anger toward others or toward the world in general. I can't relate to this symptom.*

- We have extreme reaction to changes in routine, surroundings and people. This, like some of the others, is a general autistic trait. It's summed up by the autistic credo, 'All change is bad.'

  *I do have a narrow comfort zone and generally prefer repetition of familiar experiences over new people, locations, and adventures.*

- Our conversational style is pedantic, as if we learned to speak English from watching Masterpiece Theatre. Which, in a way, a lot of us did.

  *There is some truth to this. I usually attribute it to my academic background, but perhaps I became an academic partly because it suited my conversational style. It made me a relatively good lecturer, but only an average teacher since I'm less comfortable in a dialogue than a monologue.*

- Needless to say, we don't play well with others. To quote the Aspies' TV role model, Daria Morgendorfer, 'The team is the last refuge of the mediocre individual.'

  *I am a bit of a loner, both professionally and socially, and I have rarely participated in team sports except with a measure of discomfort.*

- We're often perceived as 'being in our own world.'

  *I've often attributed it to the technical nature of my work, but I can get caught up in a scientific or computational problem to the near exclusion of all else, staying up most of the night, forgetting to eat, and generally oblivious to other people and other things happening around me. These are often productive experiences, and a part of me longs to have more of them, but they can be a strain on personal relationships, once bringing an abrupt and unpleasant end to a budding relationship when I became obsessed with a computer project for several days. I rarely exchange social pleasantries with my professional colleagues.*

At least three quarters of the above characteristics apply to me in at least some degree, although I might have slightly exaggerated the extent to which they apply to me. Whether a psychologist would characterize me as having Asperger's Syndrome is of little consequence since a diagnosis does not facilitate a treatment, much less a cure, especially in adults. Unquestionably, I have many of the symptoms, and thus I can benefit from an awareness of my limitations and seek ways to compensate for them.

These characteristics have caused difficulties in my personal relationships, but they have also affected my professional life. It is important for a scientist to attend meetings and conferences and to develop personal relationships with other scientists in the field. Securing and maintaining research funding requires cordial interaction with reviewers and staff in the funding agencies. Much science is now done by large groups, and there are personnel, organizational, and supervisory duties that require tact and good communications.

Over the course of my career, I gravitated to a style of work in which my interactions are mostly with students, and many collaborations are done over the Internet with people I have never met and thus do no interact with socially or verbally. I rarely attend scientific conferences unless I am an invited or featured speaker, which provides the needed self-confidence. I can be proud to have had considerable professional success and satisfaction despite my limitations, but without doubt, I would have done even better without this annoying affliction.

# Chapter 18

# Mathematics of Love and Happiness

> What makes us discontented with our condition is the absurdly exaggerated idea we have of the happiness of others. —Anonymous

Many accomplishments in my professional life have given me great satisfaction: getting admitted to MIT, entering graduate school, publishing my first paper, receiving a PhD, beginning my first real job at Oak Ridge, becoming a professor, getting tenure, writing my first book, taking over leadership of the plasma physics program, starting *The Wonders of Physics* program, winning a teaching award, and much more.

But I noticed that the pleasure and happiness over the attainment of each goal quickly dissipated, and I needed a new challenge. I learned to fly, I took up various new sports, and I learned to dance, but the pleasure of those achievements also waned in time.

On the other hand, I have had some disappointments, mostly in my personal life, when relationships that began with great excitement and promise eventually came to an end for a variety of reasons. I was occasionally quite devastated, but I learned that those feelings too would eventually yield to happiness, and the cycle repeated again and again.

I noticed that the happiest and the saddest times were ones of transition, and I proposed a general principle—that humans rather quickly acclimate to their current state and only respond emotionally when that state changes—or in the language of calculus, we respond to the time derivative of our circumstances. That philosophy helped get me through some bad times and kept me from developing unrealistic expectations of the happiness that would accrue from my achievements and from the lucky events that occurred in my life. Just as sadness eventually passes, so too does happiness, and one cannot expect to be constantly happy. Over the course of one's life, the good and the bad tend to balance out.

Thinking about life mathematically and developing an interest in dynamical systems primed me to respond enthusiastically when I came across a mathematical model of love affairs described in a book by Steve Strogatz.[1] Similar models had earlier been proposed by others, apparently unknown to Strogatz and certainly to me. He proposed it, not necessarily as a serious sociological model, but rather as a way to motivate students in their study of dynamical systems theory. But I immediately saw how well it described the dynamics of some of my relationships, and it resonated with my mathematical way of thinking about life and my theoretical interest in dynamical systems.

At the risk of being slightly technical, I will describe his model since it is really quite simple for anyone who understands just a bit of calculus. Strogatz imagines two lovers, Romeo and Juliet, and characterizes Romeo's love for Juliet by the variable $R$ and Juliet's love for Romeo by the variable $J$. Both variables can be either positive or negative depending on the degree of love or hate they have for one another, and they change in time according to the equations

$$dR/dt = aR + bJ$$
$$dJ/dt = cR + dJ.$$

The left-hand side is the rate of change of $R$ and $J$, respectively, and at each instant of time, they depend on the values of $R$ and $J$ in the simplest possible way, through a linear combination of the two. These equations constitute a set of coupled ordinary differential equations, which is the mathematical language in which dynamical systems are usually described.

The parameters $a$ and $b$ characterize Romeo's 'romantic style,' while $c$ and $d$ characterize Juliet's style. For example, if $a$ and $b$ are both positive, Romeo is an 'eager beaver' since he is encouraged by his positive feelings toward Juliet as well as her positive feelings toward him. On the other hand, if $a$ is negative, Romeo is a cautious (or perhaps secure) lover since he avoids throwing himself at Juliet in response to his feelings for her, whereas if $b$

[1] S. H. Strogatz, *Nonlinear Dynamics and Chaos with Applications to Physics, Biology, Chemistry, and Engineering* (Addison-Wesley, Reading, MA, 1994), pp. 138.

is negative, Romeo hates to be loved and loves to be hated. Thus Romeo can have one of four possible romantic styles, depending on the signs of $a$ and $b$, as can Juliet, and thus it is interesting to contemplate the fate of the sixteen possible combinations as well as the cases where one or more of the parameters is exactly zero.

Perhaps not surprisingly, with so many combinations, almost anything can happen, especially since the initial conditions (first impressions) also matter. If $a + d$ is negative, the end result is a state of apathy ($R = J = 0$), with neither one loving or hating the other. If $a+d$ is zero, they cycle endlessly between love and hate, but with one of their feelings lagging behind the other so that they experience mutual love only one quarter of the time. If $a + d$ is positive, their love or hate grow without limit, and they end up either in a love fest, or at war, or with one loving and the other hating. Curiously, the only static solution is apathy, and growing mutual love is ensured only if $a + d$ is positive and greater than $2\sqrt{ad - bc}$ and if they got off on the right foot (both attracted to one another). It's a wonder that good relationships ever occur.

The foregoing model is entirely due to Strogatz, whose undergraduate students are expected to deduce these results as homework in his nonlinear dynamics course. When I became interested in the problem, I decided to extend the model by considering the effect of nonlinearities and love triangles where chaos is expected both mathematically and in real life. Either effect by itself is not sufficient to produce chaos, but in combination, chaotic solutions are possible.

For a nonlinearity, I made a simple assumption that if a small amount of love from one's suitor is good, too much is smothering, and when the animosity reaches a sufficient level, they decide to stop fighting. For a love triangle, I assumed that Romeo had a mistress, whom he treats in the same way as he does Juliet, and that his two lovers are unaware of one another since that leads to the simplest such model. When Hillary Warren, a professor of communication at Otterbein University and the wife of my colleague Keith Warren, heard me give a seminar about this model, she said that I was being sexist. It should be Juliet who has another lover, and it should be a woman.

Nonetheless, the model gives rise to a variety of complex dynamics, including chaos, and it leads to some interesting and amusing conclusions about the dismal prospects of such a love triangle. The work appeared in the journal *Nonlinear Dynamics, Psychology, and Life Sciences*,[2] published by the Society for Chaos Theory in Psychology and Life Sciences, an organization of unconventional people receptive to such offbeat ideas. It didn't hurt that I'm on the editorial board of the journal. Strogatz warned me that the psychologists would take the model rather too seriously, and he was right, but like him, I considered it as an amusing exercise in mathematical analysis.

It turns out that with a bit of algebra, Strogatz's model can be expressed in the form of a single equation in which the variable $J$ does not appear:

$$\frac{d^2R}{dt^2} + \beta\frac{dR}{dt} + \omega^2 R = 0$$

where the two new parameters $\beta$ and $\omega$ are given in terms of the four old parameters by $\beta = -(a + d)$ and $\omega^2 = bc - ad$. This trick turns the sociological model involving two interacting individuals into a psychological model involving only Romeo. Juliet serves merely to provide feedback, reflecting Romeo's feelings toward her back onto himself, much like a mirror. The second derivative $d^2R/dt^2$ should be familiar to students of calculus as the rate of change of the rate of change of $R$, which for an object in motion would be the acceleration or the rate of change of velocity.

While this equation was motivated by considering love affairs, it occurred to me that it might be rather more general, describing a wide range of feelings. There are many feedback mechanisms, some within one's own head and not requiring a second person. It may be that $\beta$ and $\omega$ are more fundamentally descriptive of a person's psyche than are $a$ and $b$. You might object that $\beta$ and $\omega$ involve $c$ and $d$ that characterize Juliet, over whom Romeo presumably has no control. However, he can adapt his own style (alter $a$ and $b$) to achieve values of $\beta$ and $\omega$ that are comfortable for him, and Juliet can do the same. Sometimes this may not be possible, in which case the relationship does not 'work,' or it leads to a permanent change in $\beta$ and $\omega$. Some might call this 'learning from experience' or simply 'growing up.'

Love is one quantity that can affect happiness, but as I said earlier, it is my experience that the happiest time is when one is falling in love and the saddest time is when that love is lost. Thus I propose that happiness is given by the rate of change of $R$ or $H = dR/dt$. Then we can think of $R$ as representing a much wider range of factors whose acquisition leads at least

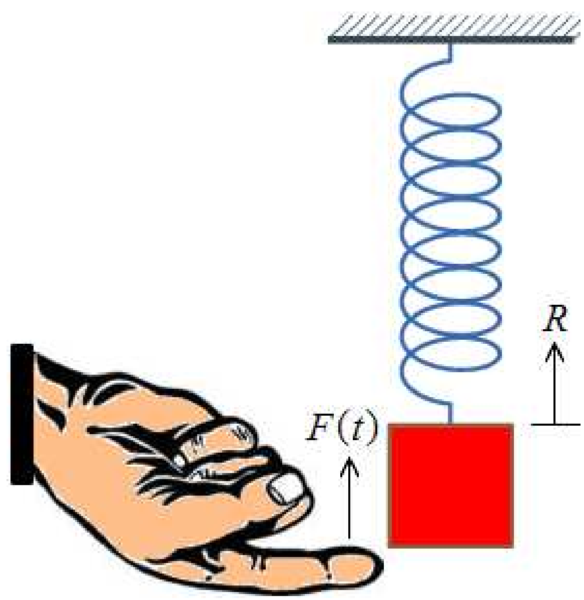
[2] J. C. Sprott, Dynamical Models of Love, *Nonlinear Dynamics, Psychology, and Life Sciences* **8**, 303–313 (2004).

temporarily to happiness, including wealth, education, health, friendships, and so forth.

A final ingredient of the happiness model is to take into account the myriad of external events that happen in life that affect one's well being such as winning the lottery, death of a loved one, and the countless small pleasures and annoyances that continually occur and over which one has little control. These factors are represented by adding a term $F(t)$ to the right-hand side of the equation to represent such factors as they occur over time:

$$\frac{d^2R}{dt^2} + \beta\frac{dR}{dt} + \omega^2 R = F(t).$$

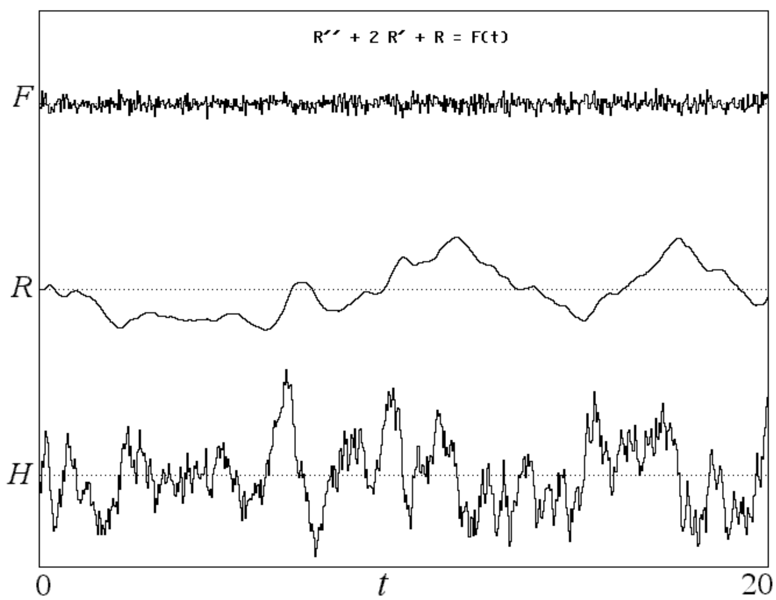
This equation is well known to students of physics as the equation for a forced, damped, harmonic oscillator, many examples of which occur in nature. Thus it is useful to provide a mechanical analogy so that the corresponding psychological quantities can be more easily visualized and understood. The standard example is a mass suspended by a spring as shown in the figure.




A mechanical model of happiness in which the 'finger of fate' lifts us up or pushes us down, and our happiness (sadness) is represented by the upward (downward) velocity of the mass.

In the absence of an external force ($F(t) = 0$), the mass rests at its equilibrium position where the upward force of the spring just balances the downward force of gravity. Its velocity is zero, corresponding to a neutral state neither happy nor sad. If it is perturbed away from that equilibrium, it oscillates with a frequency $\omega$ (in radians per second), and the amplitude of that oscillation decreases at a rate $\beta$ due to friction or air resistance. There is a critical value of $\beta$ equal to $2\omega$ for which $R$ returns to zero as rapidly as possible without overshooting. The shock absorbers of a car are designed to be critically damped to give the most comfortable ride, and an emotionally healthy individual may behave similarly to the bumps of life.

If a time-dependent external force $F(t)$ is applied, the motion is more complicated. Importantly, both the position $R$ relative to the equilibrium and the velocity $dR/dt$ tend to have a zero average after a sufficiently long time, especially if $F(t)$ averages to zero. By analogy, happiness corresponds to the velocity and averages to zero even in the presence of 'the finger of fate' which can either elevate one's condition (increase $R$) or drag one down (decrease $R$). A simulation showing the time dependence of $R$ and $H = dR/dt$ in the presence of a random $F(t)$ with zero mean and critical damping is shown in the figure.




A simulation of the happiness $H$ that results from the influence of many random events $F$, some good and others bad.

Several interesting conclusions can be drawn from the figure. The quantity $R$ corresponds to one's circumstances and is what others assume your happiness to be. It is the integral of $H$, which is how you actually feel. It is less volatile than $H$ and tends to lag behind it. The resemblance of $R$ to a stock market average and $H$ to its daily change is probably more than coincidental since stock prices are driven by fluctuations in world events ('shocks' in the jargon of economics). Bull markets and bear markets are analogous to happy and sad individuals, respectively, and neither is a permanent state.

I considered various extensions of the happiness model including nonlinearities, which can lead to oscillations even in the absence of external events such as might occur in someone with a bipolar disorder, as well as a more advanced model with nonlinearities and a third derivative $d^3R/dt^3$ which can produce chaotic oscillations. I submitted a paper including both the love and of happiness models to *Nonlinear Dynamics, Psychology, and Life Sciences*, but the editor Steve Guastello, a professor of psychology at Marquette University, suggested that I separate it into two papers, the first of which was previously mentioned, and the second of which was published in the following year.[3]

When I explain my happiness model to friends and colleagues, reactions tend to fall into one of two categories—those who say it's obvious, and those who say it's ridiculous. Two professors of social work typify the extremes. Keith Warren, a professor at The Ohio State University was sufficiently enthusiastic as to offer to collect data and coauthor a paper on the topic with me, which has yet to happen. Rosemarie Carbino, a friend and professor at the University of Wisconsin, stopped me in my tracks by saying that if I were a peasant in India rather than a white American academic, I would never propose that everyone is equally happy. I was about to admit that perhaps she was right until the next day when I happened to see in the newspaper a study showing that peasants in India are just as happy on average as urban Californians. Martin Seligman, a professor of psychology at the University of Pennsylvania, likes to say that 'depression is a disease of the affluent.'[4]

There is little evidence that rich people are any happier on average than poor people, although the newly rich certainly enjoy their good fortune for a while until they acclimate to it, and many rich people are quite devastated when financial markets take a downturn, occasionally even to the point of

[3] J. C. Sprott, Dynamical Models of Happiness, *Nonlinear Dynamics, Psychology, and Life Sciences* **9**, 23–36 (2005).

[4] M. E. P. Seligman, *Authentic Happiness: Using the New Positive Psychology to Realize your Potential for Lasting Fulfillment* (Free Press, New York, 2002).

committing suicide. Economic theory is based on the assumption that people attempt to maximize their wealth in an effort to find happiness, and perhaps they do, but their satisfaction upon acquiring that wealth rapidly fades. Since some wealthy people were significantly poorer in the recent past, one would expect a weak positive correlation between happiness and wealth if one's financial history is ignored.

There is evidence that married people are happier on average than single people, but it does not follow that getting married makes one happier. It is equally plausible that people who project a happy demeanor are more likely to attract a mate than those who appear depressed. The early stages of marriage tend to be happy, while the early stages of divorce tend to be unhappy, and so people who have repeated short-term relationships would tend to be happier when they have a partner than during the intervening times.

Some people almost take offense at the claim that happiness tends to average to zero. They never say that they are always happy or always sad, but rather that they know someone who is. However, the happiness that I am describing is the subjective feeling that one has when getting up in the morning, not the objective assessment of someone of who knows them, however well. Some people call this feeling 'mood.' My claim, arising mostly from personal experience, is that one quickly acclimates to whatever conditions life presents and thereafter responds only to deviations from that condition. Seligman calls this 'the hedonic treadmill,' although he assumes a set point not necessarily at zero and controlled in part by inheritance and in part voluntary.

My happiness paper cites studies of lottery winners, accident victims, and many others in support of this claim. Although happiness is assumed to average to zero, that does not mean that an individual is happy only half the time since long periods of happiness can be interrupted by short periods of intense unhappiness such as might accompany the loss of a loved one or other tragic event. Lottery winners typically experience an initial euphoria that quickly fades and is replaced by a prolonged period of mild unhappiness until equilibrium is eventually restored.

I once asked Richie Davidson, a long-time friend of the $14^{th}$ Dalai Lama and Director for the Laboratory of Affective Neuroscience at the University of Wisconsin and who holds an opposing view that happiness is a learned skill, if the Dalai Lama ever has his bad days. He said that he once asked him what was his best day, and he said it was today, which suggests to me that yesterday was not so good.

My happiness model has some practical implications that I summarize at the end of my paper:

- The simplest model supposes that over a sufficiently long time, people tend to acclimate to their circumstances and thus experience equal amounts of happiness and unhappiness. Therefore, constant happiness is an unrealistic and unobtainable goal.

- Suicide is an irrational response to unhappiness, similar to bailing out of the stock market at the bottom. The model predicts that if you wait long enough, happiness will return, even if only by virtue of acclimating to whatever is causing the unhappiness.

- Others tend to perceive less volatility in you than you feel since they observe primarily your responses to external events ($R$) rather than your true feelings ($H$), and therefore they often wrongly conclude how happy you are.

- Since individuals will tend to acclimate to their circumstances, long prison terms may be ineffective if the goal is punishment rather than deterrence or protection of society.

- Individuals may be characterized by two parameters: $\beta$ (how rapidly they return to equilibrium after a perturbing event) and $\omega$ (the frequency with which their feelings change). These parameters may be of diagnostic use in describing psychological health.

- Healthy individuals may have $\beta \sim 2\omega$, corresponding to critical damping, while people with $\beta < 0$ exhibit bipolar behavior. A strongly overdamped person ($\beta \gg 2\omega$) may be largely devoid of emotions and unaffected by events, whether good or bad.

- A reasonable goal of psychotherapy might be to alter the parameters $\beta$ and $\omega$ so that the patient responds to external events in a more healthy manner. It is an open question the extent to which such therapy is effective since the parameters may be largely fixed by one's personality.

Note that the model should also apply to any quality to which an individual acclimates, including wealth, health, beauty, intelligence, and spirituality, as well as the physical senses of taste, touch, smell, hearing, and sight. Thus it could be tested in a wide variety of contexts, and I would welcome a collaboration along any of these lines to test the model.

# Chapter 19

# Competition and Creativity

> Research is what I'm doing when I don't know what I'm doing.
> —Werner von Braun

When I describe my chaos research to nonscientists, I'm sometimes asked what it's good for. About once a month, a stranger—often a student apparently writing a term paper—will send an email asking me to explain the use of fractals. I'm mildly annoyed by such questions. No one asks a mathematician what is the use of triangles, or an astronomer what is the use of black holes, or a physicist what is the use of quarks. Some things are worth studying just because they are interesting and not well understood. Yet it is a fair question.

One stock answer is that chaos might be used as an encryption method for secure communications. The idea is that chaos appears random to the casual observer and thus would sound like noise if used to mask human speech. Yet the observer who knows its origin can reconstruct the chaotic signal exactly and thus unmask the signal at the receiving end.

I never found that example compelling. For one thing, the method doesn't seem secure since a determined eavesdropper could presumably perform the same decryption. Furthermore, it seems that the pseudo-random number generator available in most computer languages would serve just as well as chaos since it can reproduce exactly the same sequence of random numbers if one knows the initial 'seed,' which serves as the secret key that must be securely shared between the sender and receiver. Indeed, non-chaotic encryption schemes are already well developed and routinely used in communications.

Citing applications somehow misses the point and understates the importance of chaos, which is no less than to give a new perspective on the World. It teaches us that there are systems in nature like the weather and the economy for which long-range prediction will always be impossible but that nevertheless might be adequately modeled for some purposes by simple rules or equations, and that such systems are ubiquitous. These models are useful for short-term prediction, understanding the sensitivity to changes in parameters, discovering disallowed behaviors, and making statistical predictions.

Similarly with fractals, once one understands the concept of self-similarity and sees mathematical examples, it's hard not to notice them everywhere in nature. I began my study of fractals by reading the book *Fractals Everywhere* by Michael F. Barnsley, the opening page of which carried the following warning: 'Fractal geometry will make you see everything differently. There is danger in reading further. You risk the loss of your childhood vision of clouds, forests, galaxies, leaves, feathers, flowers, rocks, mountains, torrents of water, carpets, bricks and much else besides. Never again will your interpretation of these things be quite the same.' And so it was with me.

If there is a single lesson that my research has taught me, it is that *things change.* And they change not just in the regular way that night follows day and winter follows summer, but rather in a complicated and unpredictable way as with bull and bear financial markets, periods of war and peace, and the ebb and flow of human relationships. These changes are not random but presumably have causes from which they inevitably follow, but the tiniest cause like the flapping of a butterfly's wing can drastically alter the future. In a word, the World is *chaotic*, both in the colloquial and the mathematical sense.

Much of science has traditionally involved understanding cause and effect relationships, observing recurring behavior, and making accurate predictions. Chaos throws all that out the window. We need to ask different questions and reconsider our scientific objectives. Similarly, an understanding of fractals teaches us that some apparently well-posed questions such as the length of a river or the average size of craters on the Moon have no answer—or rather that the answers are infinity and zero, respectively. But it replaces those questions with more appropriate ones such as determining their fractal dimension.

Virtually all our modern technology has arisen through studies of systems with a small number of components interacting in simple linear ways, which means that effects are proportional to their causes, and such systems are carefully engineered to avoid chaos. You would not want to drive an automobile or use a computer that behaved chaotically. However, most things in the natural World involve many nonlinearly interacting parts, and such complex systems more often than not are chaotic.

The assumption of linearity is so deeply ingrained that we often misapply it. An example is radiation exposure. If we know that a given exposure would kill 50% of the population, linearity would imply that one tenth of that exposure would kill 5% of the population and one millionth of that exposure would kill one out of every two million people. Now it may be so, but it has not been demonstrated. It is difficult to test the effects of low levels of radiation, and so it is reasonable to set allowed dosages conservatively by assuming linearity—up to a point where the cost of doing so outweighs the presumed benefit.

However, it is equally plausible that there is a threshold below which radiation, pollution, germs, and other pathogens pose no hazard or are even beneficial. The tendency of things that are harmful in high doses to be beneficial in small doses is called *hormesis*. Although the concept is controversial, examples abound. Eating a moderate amount of food is essential for life, but too much impairs one's health. A small amount of wine is good for the heart, but too much can kill you. Every drug has a dosage above which it is toxic. Moderate exercise is beneficial, but too much can damage your body. As is often said, 'what doesn't kill you, strengthens you.'

Nonlinearities are common in nature. The Polish mathematician Stanislaw Ulam liked to say that 'the study of nonlinear dynamics in nature is like the study of nonelephant mammals in zoology.' Linearity is a convenient and common assumption, but it can be an inaccurate representation, and it often leads to nonsensical predictions. In the presence of positive feedback, a linear system will grow exponentially without limit, and in the presence of negative feedback it will die. Natural systems do neither but usually fluctuate chaotically as a result of nonlinearities and a combination of positive and negative feedback.

A linear system is sometimes misunderstood to mean one in which A causes B and B in turn causes C, and so forth. In a complex system, it is more typical for A to cause both B and C, but for B to also cause A and C and C to cause A and B. In effect a complex system is replete with feedback loops, and the causes and effects are intermingled. However, such a system could be entirely linear in the mathematical sense of the effects being proportional to their causes, in which case it cannot exhibit chaos. It can oscillate, but the oscillations will either grow without limit or decrease to extinction.

There are many types of nonlinearities in which the effect is disproportionate to the cause. The effect can increase faster than the cause, which is probably the case with pathogens. Or the effect can increase slower than the cause, which is probably more typical, and puts a natural limit on the exponential growth that would otherwise occur for a linear system. Even in the case of radiation exposure, once the dose is sufficient to kill everyone, higher doses have no additional effect. More complicated nonlinearities are possible such as a reversal of the sign of the effect as in hormesis, or even periodic reversals in the effect as the strength of the cause increases.

Society faces many problems and challenges, nearly all of which involve dynamical systems consisting of complex networks of nonlinearly interacting agents. This is the case for climate change, biodiversity, economic cycles, distribution of wealth, energy production and consumption, pollution, political instability, wars, and much more. We long for a stable state in which things are not changing, and great effort is expended in social engineering by legislation, advertising, applying technological fixes, and so forth to bring that about. Yet it never happens, and it is probably a good thing that complex systems behave chaotically since that is the mechanism by which they self-organize and adapt—or perhaps is a result of it.

Linear thinking can make us pessimistic about the future since we presume that whatever causes an undesirable effect will do so at an increasing rate if the cause increases (think of carbon dioxide causing global warming). Nonlinear thinking is even scarier since we fear threshold effects such as the tipping point that Al Gore describes in global warming where the system suddenly flips to a much less desirable state from which it is difficult to recover. In nonlinear dynamics, the flip is called a 'bifurcation,' and the difficulty of recovering is called 'hysteresis,' and such behavior is common in mathematical models.

But since a complex system involves a myriad of causes and effects with numerous feedback loops, both positive and negative, it tends to adapt and self-organize often in quite unexpected ways as the agents act to minimize the undesirable impacts. This ability coincides with the presence of weakly chaotic dynamics, although one should not say that one is the cause of the other. Furthermore, natural systems more often than not are dominated by negative feedback and saturating nonlinearities. Thus I am more optimistic about the future than many of my friends.

My dear friend Myrna Casebolt likes to say that many of the World's problems could be solved if we would all just sit at the table together and discuss our disagreements and at least agree to disagree. It is tempting to assume that cooperation is good and competition is bad. Yet biological evolution depends crucially on competition and survival of the fittest, as does technological innovation, scientific discovery, generation of wealth, and many other things.

Competition is a form of negative feedback, but negative does not mean bad; rather it means stabilizing which limits growth, whereas positive feedback is destabilizing and encourages growth. If the factor that is growing is pollution, then it would be bad, but if it is wealth or knowledge, then positive feedback is a good thing. Note also that in a complex system, the feedback loops can be convoluted and that two negative feedbacks can make a positive. If A is fighting with B, and B is fighting with C, then A is helping C. On the other hand, two positive feedbacks cannot make a negative. Thus you might conclude that positive feedback is more common, but that is not the case since there are two ways to combine a negative and a positive, $+-$ and $-+$, both of which give a negative, while two positives, $++$, and two negatives, $--$, give a positive. Negative feedback is probably more common since positive feedback requires an external source of energy or resources and those are limited.

My chaos research has taken two rather opposite directions. In the spirit of physics, I have devoted much effort to discovering the mathematically simplest systems of various types that can produce chaos. I have already given examples in the generation of strange attractors, models of romantic relationships, and fluctuations in individual happiness.

At the other extreme, I have been interested in the dynamical behavior of large networks of nonlinearly interacting agents, called *artificial neural networks* (ANNs) since they crudely model the operation of the brain, but they could just as well represent interacting species in an ecology, interacting traders in a financial market, or interacting politicians in the Senate, for example.

One of the first questions I asked was how complex such a network had to be before the probability of it exhibiting chaos was essentially 100%. With my student Dave Albers and an economics professor from the University of Houston, Dee Dechert, who was interested in chaotic financial markets and using ANNs to predict market moves, we examined millions of ANNs with randomly chosen connection strengths between the neurons and catalogued them according to the nature of their dynamics. The neurons used a sigmoid nonlinearity and were connected with a relatively simple form of feedback as required for chaos.[1]

I have often described this line of research as the study of models without regard to what it is they are modeling. Buried in these millions of ANNs are ones approximating every dynamical system that occurs or could occur in nature since ANNs are known to be 'universal approximators.' Rather than training the ANNs to perform some desired task as is customary, we simply connected the networks randomly and observed how they behave on average.

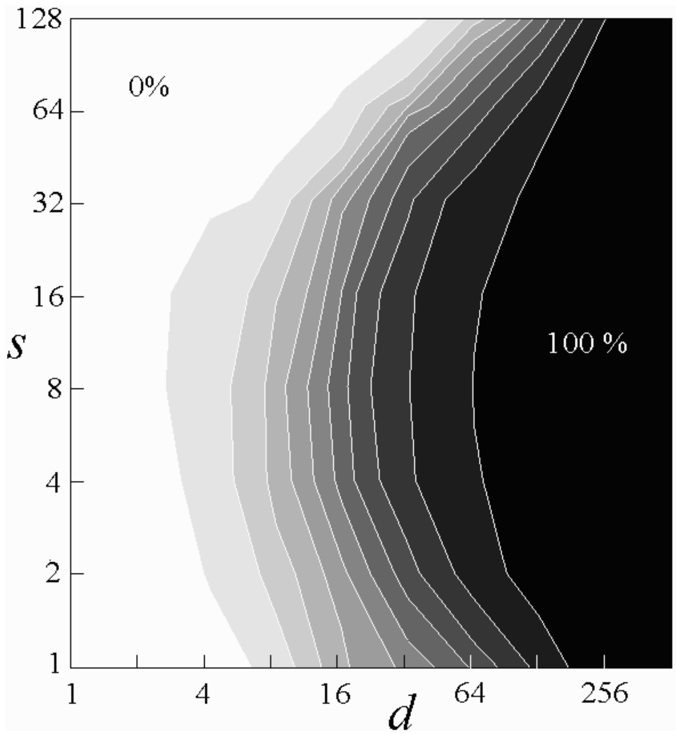
We noticed immediately that a combination of negative and positive feedback is required to get non-stationary temporal dynamics, and so we chose to use an equal amount of each. By analogy, the brain has excitatory and inhibitory connections between its neurons. Both cooperation and competition are required to make the system fluctuate in a realistic way. The positive feedback is the source of energy or resources that keep the system from dying (think of sunlight in an ecological system), and the negative feedback is what limits the growth (think of competition for food in an ecological system) and allows it to oscillate.

We also had to choose the average connection strength between the neurons and found that connections that are too weak or too strong suppress the chaos and ultimately the temporal dynamics, but there is a wide range of intermediate connection strengths where chaos is common and relatively insensitive to the strength. Not surprisingly, as the complexity of the network increases, the likelihood of chaos increases, reaching essentially 100% when the dimension of the system, which is a representation of the number of interacting agents, reaches about a hundred. Those results were published in an economics journal.[2]

Following that was a series of papers discussing other mathematical properties of these large chaotic networks. For example, we discovered that under typical conditions, although the probability of chaos approaches 100% as the networks become more complex, the magnitude of the chaos as quantified by the Lyapunov exponent decreases. The Lyapunov exponent is roughly the

[1]These are typically feedforward networks with a single hidden layer of neurons that generate the next term in a time series based on some number $d$ of previous terms.

[2]W. D. Dechert, J. C. Sprott, and D. J. Albers, On the Probability of Chaos in Large Dynamical Systems: A Monte Carlo Study, *Journal of Economic Dynamics & Control* **23**, 1197–1206 (1999).




Evidence that for intermediate connection strengths ($s$), a network with sufficiently many interacting agents ($d$) is usually chaotic.

inverse of the time over which prediction is possible. The networks evolve toward a state of weak chaos, dubbed 'the edge of chaos' by Doyne Farmer in reference to computer experiments of Christopher Langton at the Santa Fe Institute.

I proposed a mechanism by which a complex ecological or financial network would naturally evolve toward a state of weak chaos,[3] which addresses a problem in ecology known as the *principle of competitive exclusion* where all but the dominant species in a competition go extinct. In my model, when one agent approaches the point of extinction, other agents cease to compete with it. It no longer represents a significant threat, source of food, market for one's products, or whatever. In effect, it is a nonlinearity that allows species to coexist and the system to self-organize.

The idea that chaos is beneficial in natural systems is now widely ac-

[3]J. C. Sprott, J. A. Vano, J. C. Wildenberg, M. B. Anderson, and J. K. Noel, Coexistence and Chaos in Complex Ecologies, *Physics Letters A* **335**, 207–212 (2005).

cepted. It was once thought that a healthy heart had a regular sinus rhythm, but it was discovered that perfect cardiac periodicity is a pathological condition, and that a healthy heart is weakly chaotic. Periodicity implies that the heart is not responding to its surroundings. On the other hand, a fibrillating heart is strongly chaotic and presages death.

Weak chaos allows the exploration of a wider range of conditions, while still retaining a degree of memory and predictability. Similarly, a prey in the wild has a better chance of eluding a predator if its fleeing motion is chaotic, but it must retain some memory of what movements it has previously made and how successful they were. In this case, evolution selects for weak chaos since it increases the chance of survival and hence reproduction.

These ideas raise the most profound question of all. Since the human brain is a large network or nonlinearly interacting neurons, is it chaotic, and if so, is that chaos beneficial? Clearly, too much chaos in the brain is undesirable, and such people end up in asylums or perhaps prison. They behave unpredictably and have impaired memory that inhibits learning. But weak chaos might aid thinking or even be indispensable to it since it allows creativity and prevents one from getting stuck in a rut endlessly regurgitating the same old ideas.

One might argue that computers, which mimic some features of the brain, are not chaotic, and thus chaos is not essential for thinking. But a computer exhibits no creativity and only performs repetitive tasks that it is programmed to do. Furthermore, it is following a program supplied by a human, and the program usually involves nonlinearities in the form of branching statements (if–then–else) or explicit mathematical nonlinearities such as $x^2$, $\sin x$, and so forth. As such, it is capable of modeling chaotic and even self-organizing systems.

One indication of chaos in the brain comes from electroencephalograms (EEGs), which are electrical signals obtained from electrodes attached to the scalp and that average the electrical voltages from large groups of neurons in the vicinity of the electrodes. As with heartbeats, the signals often have a nearly periodic structure, usually called ‘waves,’ although there is little evidence that they propagate significantly in space. The fluctuations are not perfectly periodic, however, and the resulting plots appear chaotic. The oscillations are more nearly periodic in anaesthetised and comatose patients. There have even been attempts to estimate the fractal dimension of the apparent strange attractors and to use the results for diagnostic purposes.

Prior to his death in 2005, the eminent medical physicist John R. Cameron used to give regular guest lectures to my physics class. One popular lecture cited the controversial but plausible evidence for radiation hormesis, and he was quite convinced that low levels of radiation are beneficial to health through stimulation of the immune system.[4] He believed that the evidence for this has been downplayed and that research in this area is underfunded because it is not 'politically respectable.'

As an aside, I should point out that the word 'radiation' is used to describe a wide variety of physical phenomena ranging from the electromagnetic radiation from cell phones to the very high energy cosmic rays that bathe the Earth. There is no convincing evidence and no plausible mechanism whereby the low frequency radiation from cell phones and similar devices pose any health hazard, no matter what their intensity. Albert Einstein received the Nobel prize for his work in 1905 in which he showed that the energy of individual photons is proportional to their frequency. Only *ionizing* radiation in the far ultraviolet and higher, including X-rays and gamma rays, has the ability to disrupt molecules and thus cause genetic damage. The photons emitted by a cell phone would need to be a million times more energetic for that to occur.

Another of John Cameron's popular lectures was titled 'The Physics of Imagination and Creativity' in which he argued that electrical noise in the brain is responsible for our ability to imagine new things and that a combination of imagination and knowledge leads to creativity.[5] He thought there are individual differences in the level of such noise and its effects, causing some people to be more imaginative than others, and that highly imaginative individuals tend to have bad memories and vice versa. He proposed experiments in which subjects would be exposed to randomly pulsed magnetic fields while being tested for short-term memory. He went on to point out that medical schools select individuals with good memories, which benefits the patient since no one wants a doctor with lots of imagination and a poor memory, or as he humorously put it, 'I have an idea; bend over.'

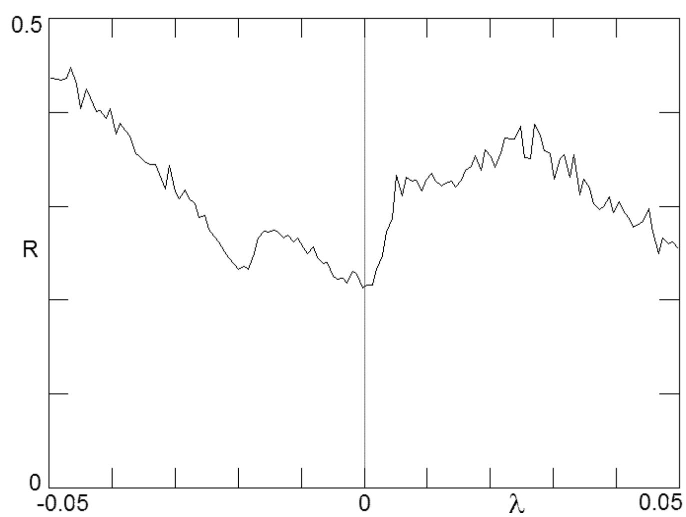
John Cameron didn't know much about chaos, or at least he didn't talk about it, but I suspect he would have been as happy to attribute imagination and creativity to chaos as to noise. In fact, as a practical matter, it is difficult

[4]Some of the arguments for radiation hormesis are detailed in J. R. Cameron and J. E. Moulder, Radiation Hormesis Should be Elevated to a Position of Scientific Respectability, *Medical Physics* 25, 1407–1410 (1998).

[5]These ideas are described in J. Cameron, A Proposed Model for Imagination and Creativity, *Wisconsin Academy Review* (June 1988), pp. 33–36.

to distinguish the high-dimensional chaos that occurs in a complex dynamical system from noise. Some people think that most noise is really chaos in the sense that it is produced by classical deterministic processes. Only in the atomic realm does quantum mechanics postulate true randomness, and even there it has its detractors including Einstein who insisted that 'God does not play dice with the Universe.'

I have long been intrigued by the idea that weak chaos in the brain may be beneficial and have tried to demonstrate that several times with artificial neural networks. Most recently I had the idea to train an ANN on time-series data from a dynamical system that is just at the onset of chaos.[6] During the training, the network passes through regions of periodicity (a negative Lyapunov exponent) and chaos (a positive Lyapunov exponent). I collected data on the learning rate as a function of Lyapunov exponent for three million instances of the training and was able to show that strong chaos is detrimental to learning but that the learning is enhanced if the Lyapunov exponent is only slightly positive.




The learning rate versus Lyapunov exponent suggests that learning is enhanced when an artificial neural network is weakly chaotic.

I don't know where I fall on the spectrum of imagination and creativity, but I am somewhat comforted by the thought that my poor memory may

[6]I used the logistic map $x_{n+1} = Ax_n(1 - x_n)$ at the accumulation point of $A = 3.5699456718...$ where the Lyapunov exponent is exactly zero and the attractor is a Cantor set.

have a redeeming compensation. I recently had a dream in which I woke up from a dream, and that reminded me of a fractal and led me to wonder how many levels of dreams within dreams are possible for someone sufficiently imaginative. Many of my technical papers deal with unconventional topics, and nothing gives me greater pleasure than having a good idea that seems not to have been previously explored. Perhaps that's the best use of chaos that I can imagine.

# Chapter 20

# Retirement

> A man of science past sixty does more harm than good. — Thomas Huxley

For most of my career, I assumed I would never retire. I loved almost everything about my job and was paid generously for doing what I most enjoyed. I was proud to be a professor at a major research university and could not imagine being old and unemployed. I had always said that being a professor is the best job in the world and the closest thing I could imagine to not working. There is no mandatory retirement, good pay, few assigned duties, and many of my colleagues decades older were still going strong. Why would I ever want to retire?

I suppose the first thoughts of retirement came when Donald Kerst retired in 1980 at the age of sixty-eight. He was thirty-one years my senior, a scientific role model, and a father figure to me. Just before retirement, he was as engaged and scientifically active as ever, although he had bought a nice sailboat and a second home in Florida where he spent long summer vacations. With a named professorship, he had seldom taught regular courses and spent much time traveling to conferences, consulting, and serving on review boards, much of which could be done from his base in Florida just as well as from Madison. The plasma program at Wisconsin was on solid footing with new young faculty including Dick Post, Stewart Prager, and myself.

Kerst celebrated with a retirement banquet, for which I was the master of ceremonies, and he shifted his administrative responsibilities to me, but he continued to be as interested and nearly as involved in the research as ever, although his presence on campus was considerably less as he began spending ever more time in Florida. After retirement, he still spent about half his time in Madison, and we paid him as a consultant from our DoE research grant. It was an odd experience for me to be the one who determined his salary as a consultant. He had commented in the past that one should always be good to those who work for you because someday you may work for them, and this was not the first time he had found himself in that situation, but it was a first for me and a slightly un-nerving experience.

When he was in Florida, he would make frequent phone calls inquiring about the progress of the research. He seemed more relaxed, and I could see he was enjoying retirement. As I assumed the administration of the plasma grant, I realized what a burden it must have been for him to have done that for so many years, although I never heard him complain about it, and I suspect it was less burdensome in his younger years when there were fewer regulations, less paperwork, and more administrative support.

As the years went on, I watched many other colleagues retire, some rather young, and others after long careers. Many left Madison or just disappeared, while a few others continued to be seen on campus as if little had changed. Not surprisingly, I noticed that those who seemed less engaged and less satisfied with their career tended to retire early, while those who seemed to enjoy their work continued the longest.

My friend Robin Chapman was one of those who retired early, although she was an exception to my observation since she seemed to enjoy her work. Despite being my age, she retired while still in her 50's as part of a deal to open up a position for a new faculty member in the Department of Communicative Disorders and to pursue her many interests such as writing poetry. She was one of those who continued her presence on campus and even continued as principal investigator of a research grant, but she seemed to value greatly the freedom that retirement brings since she was newly married and enjoyed traveling.

Still I felt I was at the peak of my second career after switching from plasma physics to chaos research and starting *The Wonders of Physics* only a decade earlier. I was regularly teaching the introductory courses, immensely enjoying the lectures and demonstrations, had shed most administrative duties, and was successfully avoiding most committee work and grant writing. I just didn't feel old enough to retire, and I didn't see what it had to offer in my case.

I had heard some older colleagues say that they had retired because they were losing money with each year they worked. At first it seemed like an exaggeration, and I could not see how that could possibly be. I began to ask people why they chose to retire, and I got a wide variety of answers, including the financial advantages.

I began discussing retirement with Karen Holden, an economist friend in the School of Human Ecology, and a specialist in the effects of social security and pension policy on economic status after retirement and widowhood. She was thinking about her retirement and encouraged me to do so too. I thought that I should probably retire when she did since she was two years younger and more than anyone would know when it makes financial sense to do so. As it turned out, I preceded her in retirement by a year.

Finances were never a major consideration in my retirement, however. I had been single for most of my professional life with no dependents, led a fairly frugal lifestyle, and had more than adequate investments. The larger issue was the slow accumulation of minor aggravations and the realization that I was past the average retirement age for faculty at Wisconsin (64.4), well past the median age, and with thirty-five years of service, I had been on the faculty considerably longer than the average of 28.6 years. I was also approaching the age (65 years and 10 months) at which I could take full social security benefits without penalty, and that seemed like a subtle hint that the federal government thought it was time for me to retire. Although I did not feel old enough to retire, it was hard to ignore the calendar.

Even a job as idyllic as mine had its aggravations, although I never for a moment thought that I would be happier doing something else. Some would say I was spoiled, but I prefer to think that I had just acclimated to the good life I had and only noticed when things were not quite ideal in accordance with my theory of happiness.

My only specific duty was teaching. For the last two decades of my career, I had settled into teaching the large introductory courses for non-physics majors since I enjoyed lecturing and doing demonstrations, and the material was easy and familiar. The course met for fifteen weeks each semester with two lectures a week, often the same lecture given twice in succession since the enrollment was larger than our lecture hall could accommodate (300). Generally, two professors were assigned to these courses, and we would share the lectures. Thus, I only gave fifteen lectures each semester, or thirty a year, and they required no preparation. Yet the thought that those were thirty days a year that I had to be there at the appointed time seemed like a burden and imposition. Since I was not spending much time preparing lectures and was not employing the new teaching technologies and methods, I started to worry that my lectures were getting stale, although I continued to get reasonably good student evaluations.

More annoying was the work I had to do for the course outside of lectures. I had to write and administer many of the exams, assign homework, maintain the course grades and website, oversee the teaching assistants (TAs) who taught the discussion sessions and labs, and deal with the many non-physics issues that the students brought to me. The students were always concerned about their grades, and there was a constant string of students asking what they can do to improve their performance and then complaining when they didn't get an A in the course as they had become accustomed to in high school and in their other college courses where memorization of the material would suffice.

For some of those years, I had a head TA to shield me from much of the aggravation, but I acclimated to that as well, and it was a shock when Del Marshall graduated and left two years before my retirement since he was an especially helpful head TA. I told our Department Chair, Sue Coppersmith, that I would probably continue teaching forever if I could just walk in and give the lectures and leave all the other work for others. Yes, I was spoiled, and there is no way I can justify complaining about the small amount of work I was required to do.

I did work long hours, often at home, and often in the evenings and on weekends, but the majority of my time was spent on research and writing rather than teaching. I hesitate to call it work since it was completely at my initiative and uniformly pleasurable. However, there was an increasing burden of reporting that somehow seemed more obnoxious than would be indicated by the limited time that it consumed.

I was bothered by the sense that my ethics and dedication were being questioned. We had to fill out time sheets every month listing how many vacation days and sick days we had taken that month. I had no idea how to apply that concept to a job in which thoughts of work were never far from my mind. I didn't go to my campus office every weekday, but I more than compensated for that by working evenings, weekends, and holidays, mostly at home or with my laptop computer wherever I happened to be. Through my entire career, I never claimed a vacation or sick day, and I have no feeling of guilt about that. I was rarely sick, and I went to work on several occasions when most people would have stayed home in bed. Like most faculty, I was only paid for nine months each year, but I continued working through the summer just as during the year except without formal classroom teaching, often taking one or two months summer salary from our plasma research grants.

Since I usually co-taught with another professor, there would be frequent blocks of a month or more when I did not need to be on campus or even in Madison, and I sometimes traveled during those times, but far less than some of my high-energy physics colleagues whose research was done in Europe. I wrote a good portion of my *Chaos and Time-Series Analysis* book while in Switzerland. Then some rules were passed down saying that one needed to inform the Department Chair to be absent from campus, and there were limits on the duration of such absences without special permission. Such rules seem completely reasonable and would certainly accompany almost every other job I can imagine, but they felt like an imposition, even though no one seemed interested in enforcing them. It left me with the feeling that my work ethic and commitment to my job were being questioned. This was about the time that criminal background checks were instituted for all new hires, including faculty, as a result of the criminal conviction of several faculty members.

Then came effort reporting. Just before I retired, someone in the federal government decided that faculty and staff paid by federal grants should be made to report twice a year the percentage of their professional activities devoted to various activities. I'm sure this was well-intentioned and probably prevented some abuse in which faculty were claiming more time spent on each of their numerous projects than was actually being spent or charging time to one project that was actually spent on another, but it was complicated, and it felt like an erosion of trust. We had to take an on-line course in how to fill out the reports, and even then we were advised to get help lest we answer the questions inappropriately. After going through the first one of these and certifying that I was spending something like 12.34% of my time on physics outreach, I wanted more than ever to retire.

I had a good sense of what retirement would be like. I had taken my first and only sabbatical in the spring semester of 2001. It was in the midst of writing my *Chaos and Time-Series Analysis* book. I did much work at home and took about four one-week trips to the summer resort town of Bayfield, Wisconsin where I rented a house in the dead of winter and holed up there writing without distractions. It was a very productive time. I had also come to relish the summers in Madison since I didn't teach then and there were no Department meetings or committee work. I thrived under the lack of structure and got a lot of research done during those times. I really enjoyed having a calendar free of appointments and being able to decide each day when to get up in the morning and how I would spend the day. I viewed retirement as an unlimited continuation of the sabbatical and summer freedom and an opportunity to write and concentrate on research without any distractions. It was sounding better and better the more I thought about it.

Around the summer of 2007, I crunched the numbers and estimated that if I retired in a year, the income from my State of Wisconsin pension would be about 79% of my current salary and social security would add another 23%, and so I was at the point where I could retire without losing any income. Furthermore, the income from the pension would track the stock market, and social security would track the cost of living, both of which were increasing faster than faculty salaries. It turned out that a serious recession hit in 2008, but by state law, the pension can never drop below its initial value, and so it turned out to be ideal timing, and the actual pension was closer to 88% of my final salary. I was also eligible for medicare, and my unused sick leave would pay for an estimated sixty-nine more years of supplemental health insurance.

Once I began thinking of turning in my course grades in May of 2008 and then starting a summer of freedom that would never end, it was hard to turn back. My only hesitation was the fact that my self image was so much tied up with being a university professor. However, retired faculty are routinely given appointments as emeritus professor, which is actually an unpaid academic staff position with all the accompanying privileges. I would still have the professor title, still have my office, email address, internet access, free bus pass, use of the library, secretarial help, liability insurance in case anyone was injured in my public lectures, and even parking if I wanted it. I was assured that I could continue working with undergraduates, even giving them grades and course credit for directed study. In short, I would have everything that is important to me. The only possible problem was that emeritus professors are not part of the graduate faculty, and so I could not serve as the official advisor for graduate students, but I had not done that for about ten years since I did not have funds to support them.

I began telling various colleagues of my intention. Most thought it was a great idea and wished me well. I thought I should I warn Sue Coppersmith, the Department Chair of my intentions early so that she could plan for my absence. She was very supportive and said I could retire at my convenience without concern about the effect on the Department. We had just hired a number of new young faculty members, and so my retirement would have little effect on hiring or on staffing the courses. The only person who seemed concerned was Mary Anne Clarke, the Department undergraduate course administrator, who thought my absence from the teaching program would be a loss, but she was otherwise happy for me.

Although everything pointed to the wisdom of retiring in July of 2008, it was still hard to write the letter of resignation. I was giving up something that had defined who I was for the past thirty-five years. During February and March of 2008, George Rowlands visited with me to work on some research. He had retired about ten years earlier from the University of Warwick, and I really liked the unstructured life he was living with travel and focus on research. I began writing a new book, *Elegant Chaos: Algebraically Simple Chaotic Flows*, and promised delivery by the end of 2009. Also my fiancée (and current wife) was entertaining a postdoctoral job offer from the University of Minnesota. When it became evident that she should take the job, I composed my letter of resignation on March 6, 2008, the same day she accepted her offer, to show support and so that I would be more free to travel to Minnesota.

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March 6, 2008

Prof. Susan N. Coppersmith
Chair, Department of Physics
University of Wisconsin – Madison

Dear Sue:

With this letter, I am announcing my retirement from the faculty of the University effective July 26, 2008 (last work day July 25th). I am retiring in order to devote more time to research and writing and to facilitate a more flexible travel schedule. I intend to continue with the yearly presentations of The Wonders of Physics, supervising undergraduate students in directed study, and organizing the Chaos and Complex Systems Seminar. I may be willing to provide compensable services at some time in the future.

It has been a pleasure and honor to serve on the faculty for 35 years, and I especially appreciate the pleasant and flexible work environment and the freedom to pursue diverse academic interests and unconventional outreach activities. I believe the Department is in good hands with the new cadre of exceptional young faculty, and I wish you all the very best.

Sincerely,

Julien Clinton Sprott
Professor of Physics

One of the hardest letters I ever wrote.

Once the die was cast, there was no turning back, and I began looking forward to the event. I discouraged any celebrations since I did not view it as the end of a career but rather as a milestone and a move that would enable me to devote more time to research and writing. Bassam Shakhashiri referred to me as ‘having been promoted to emeritus professor,’ and I rather like that description. Due to a snafu in our Physics Department office there was a delay in my emeritus appointment, but it finally arrived in September of 2008.

The only significant celebration was a Department lunch that is given every spring in honor of that year’s retirees. David Huber and I shared the honor in 2008, and I had the chance to speak about five minutes summarizing what is written above and thanking my colleagues for their tolerance in letting me ‘do my thing’ and never leaning on me to be the Department Chair. Actually, only a handful of the faculty attended, but my plasma colleagues were there. The ceremony was presided over by Lee Pondrom, and I commented that he was already a professor in our Department when I started graduate school as was Dave Huber who taught one of the first courses I took at Wisconsin. Thus I felt young in their company, but I still felt I was doing the right thing by retiring in good health at an age where I could enjoy the freedom that retirement affords.

There were a few other minor events honoring retirees. The Dean of the College of Letters and Science, Gary Sandefur, invited a small group of us to have breakfast with him at the University Club. It turned out to be a low key appeal for financial donations to the College. The new Chancellor, Biddy Martin, hosted a reception for recent retirees at her residence, at which there was nice finger food and a short speech about how grateful she was for our many years of dedicated service. It was an opportunity for me to tell her about *The Wonders of Physics* program, of which she was only vaguely aware. She said to be sure to invite her to the next presentation, which I did, but she never responded or attended. I’m sure she had more important things to do. She did apologize for not attending when I met her in July of 2011 shortly after she announced her resignation as chancellor to become the president of Amherst College.

Some people lapse into a state of relative inactivity after they retire, and they tend to die rather soon thereafter. Others embark on a second career, join the Peace Corps, pursue long-postponed hobbies, or move to a place with a better climate. Many view it as a chance to read and learn new subjects, even auditing courses on campus, and are proud of keeping their minds active. I have taken a different tact and have a slightly perverse view of how one should spend one's retirement years.

Learning is a matter of rearranging the connections between neurons in one's brain, and it is an activity of paramount importance early in life since it dictates how productive one's life is likely to be. But within minutes of death, all those neural connections are destroyed. Thus it seems to me that the older one gets, the less important it is to learn new things and the more important it is to exploit and share the knowledge that one has gained over a lifetime. Thus I am increasingly resistant to learning new things, but I feel an urgency to continue my research, to publish books and papers including these memoirs, and to give lectures.

As I write this, I've been retired for three years, and I can make some general observations. There is nothing about life before retirement that I miss, and my life now is much like I expected. One quickly acclimates to the reduced responsibilities, and it is hard to see how I would ever find the time to do all the things I used to do. It is a myth that one has a lot of free time in retirement. I imagined lying in my hammock all day reading novels or perhaps some of those humanities texts I struggled to master while at MIT and kept on my bookshelf all those years, but the time gets gobbled up just as it did before but in a more relaxed and unstructured way. However, one has more freedom in how that time is used, and I revived my interest in ham radio, for example. I have been more productive in my research than before, and I have done more writing, including finishing the *Elegant Chaos* book, several books with Elhadj Zeraoulia, and especially these memoirs.

I spent a lot of time traveling to Minnesota and elsewhere, and it is nice not to have to ask anyone's permission or to make arrangements to cover classes and other duties in my absence. It is convenient not to have to schedule travel around classes and other commitments and to take advantage of the weather and vacationing while others are working or studying. I gave up my parking spot on campus and learned to ride the (free) city bus. If it's raining or bitterly cold, I can spend the day at home. I still review a lot a papers for journals, but I don't have to report my activities and effort to anyone. I go to campus when I feel like it, and I return home when I feel like it, rarely spending more than a few hours on campus each day.

In 2009, the State instituted ten mandatory furlough days each of the following two years (two weeks unpaid vacation or a 5% salary reduction, depending on your point of view). Not only that, but in any week in which a furlough day occurred, workers were asked to certify that they did not work more than thirty-two hours that week, whatever 'work' means for a scientist much of whose work is mental. One was faced with lying on the forms, which is unethical, or not thinking about science for 136 hours that week, which is impossible. Our secretary sent around a notice that we were not allowed to work on furlough days including reading our email. I thought it was a joke and replied that 'I'm not on the payroll, and so no one can stop me from working as much as I want.' It turned out not to be a joke. People had been reprimanded for reading their email on furlough days. I'm relieved that such silliness is a rapidly receding memory no longer of concern to me.

# Chapter 21

# Return to Radio

> I think the primary function of radio is that people want company.
> —Elise Nordling

Amateur radio was a formative hobby in my teenage years, but it was only a hobby, although I might have had a different career in its absence. When I left for college in 1960, almost six years after getting my ham radio license, there was no longer much time for hobbies, and it was difficult to assemble a station and antenna while living in a crowded dormitory. MIT had a nice club station, W1MX, and I operated it a couple of times, but it was on the other side of the campus, and I was not one to join clubs. Except for the summer of 1961, I only returned to Memphis for brief periods, and my parents soon sold most of my radio equipment except for a few items that I stashed away for later use.

When I began graduate school in 1964, I had even less time and inclination to resume operating even at the club station W9YT located in the Electrical Engineering Building. However, in 1965, I moved into an apartment after living in the dormitory the previous year, and for the first time it was possible to set up a simple station. By that time, solid state gear was beginning to be available, and I splurged and purchased for about $400 one of the first all solid state amateur radio receivers, a Davco DR-30. It was small enough to hold in my hand and weighed about seven pounds, quite a contrast to the bulky vacuum tube receivers that most hams had previously used. For a transmitter, I converted one of the World War II surplus ARC-5 Command Sets that I had stashed away, and for an antenna, I put a thin, nearly invisible wire up the side of the apartment building. It was a crude setup that I used rarely to make only a handful of contacts during my five years as a graduate student.


The Davco DR-30 solid state receiver I purchased in 1966.

When I moved to Oak Ridge in 1970, I lived for two years in a rented house with several tall trees in the yard from which I strung a 68-foot dipole antenna for use on the 40-meter and 15-meter amateur bands. With the ARC-5 Command Set and Davco receiver and the spare time that the new job afforded, I was able to contact people from around the world using Morse code since the Command Set did not have voice capability. I might have been even more active had I not taken up a number of other new hobbies including flying and spelunking.

When I returned to Madison in the summer of 1972, I moved into an apartment where I lived for the next fourteen years, but it was not until 1980 that I tried to get on the air again. By that time, solid state transceivers were widely available, and I purchased a Century 21 transceiver for about $300 from Ten-Tec, a company based in Sevierville, Tennessee, not far from Oak Ridge. It was limited to code operation and had a maximum output power of only about thirty watts. The only antenna I could manage was a thin wire strung from the second-floor balcony to a nearby tree, but I made quite a few contacts around the country and some foreign stations mostly on the 15-meter band.

When I was hired onto the faculty at the University of Wisconsin in 1973, I realized that I would probably spend the rest of my life in Wisconsin. At


The Ten-Tec Century 21 solid state transceiver I purchased in 1980.

the time, I held the call letters K4BOM, issued in Tennessee, and it was necessary to use K4BOM/9 since Wisconsin is in the ninth call district. Furthermore, I had no legal residence in Tennessee, and so I used that as an opportunity to change to better call letters as was required in those days. I had earned an amateur extra class license before almost anyone else since at the time it didn't confer any additional privileges, and so few people bothered to upgrade. As a result I was able to choose any call letters that were not in use. I simply went down the alphabet, starting with W9AA until I came to the first one that was free, W9AV. I suppose it was first held by someone a hundred years ago who had died long ago. It is considered a prestigious call by those who know the history of such things. The official station of the American Radio Relay League is only W1AW. For my entire adult life, my automobiles have had amateur radio license plates, first with K4BOM, and then with W9AV.

I also revived one of the transmitters that Quent Cassen and I had earlier built for use in his car and used it for occasional voice communications on the ten-meter band from my apartment. I had a second transceiver in my car on the same frequency that consisted of a modified citizen's band (CB) radio much like the one we modified and mounted on Quent's bicycle twenty-five years earlier, but with a more modern solid-state design. Unfortunately, the one in the car was stolen by a thief who was probably surprised and annoyed that it didn't work as a CB. I listened for a few weeks on the ham frequency for which it had been retuned, hoping to hear it, but it probably just ended up in the trash.

This was also about the time I became enamored with personal computers, and it was natural to combine the two hobbies. I wrote software for sending and receiving Morse code, and then it was a small step to combine the two and program the computer to make contacts automatically. It didn't work all that well, but in 1981 I published an article about my 'QSO Robot' in the premier amateur radio journal, *QST*.[1] The novelty of that wore off within a year, and I soon lapsed into another period of operating inactivity.

In September of 1986, I finally purchased my first and probably last house. It was on a lot with many tall trees, although it was at the bottom of a large hill, rather than at the top which would have been a superb location for an antenna. Within the year, I had strung a 102-foot all-band dipole antenna (called a 'G5RV') between the trees and gotten back on the air. Even with the low power and modest equipment, I was able to contact stations around the world. It is well-known that the antenna is the most important part of an amateur radio station. After about two years of occasional operation, the antenna fell down and the tuning knob on the Ten-Tec froze up, and so my last contact for quite a while was in January of 1989.

It's hard to understand where the next twenty-one years went, but I usually thought about ham radio only once a month when *QST* arrived in the mail. I had become a life member of the American Radio Relay League back in 1971 by paying twenty years of dues, and that kept *QST* coming and kept me in touch with all the new facets of the hobby such as digital and satellite communications. I would occasionally think that I should buy some state-of-the-art equipment and put the antenna back up, but I just never got around to it, and life was busy. I kept telling myself that I would get back on the air after I retired.

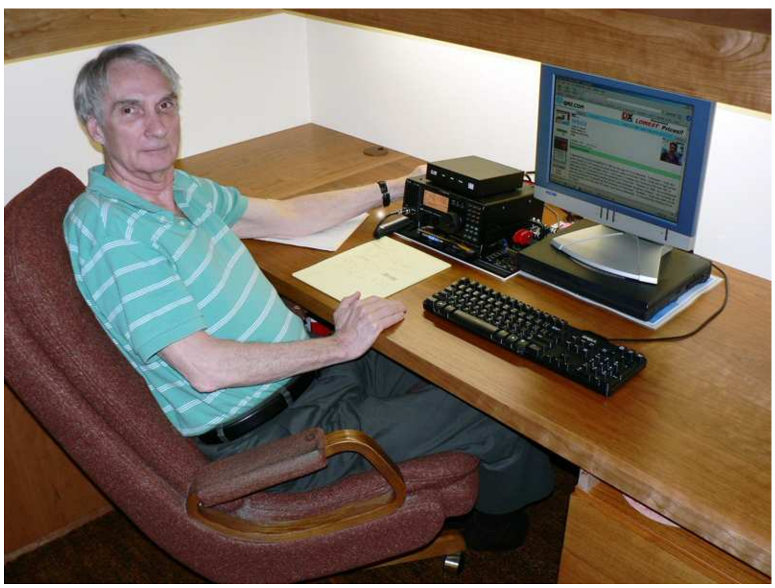
In early 2010, I had been retired for over a year and had just finished remodeling the study in which my radios were kept just off the living room of the house. The room also contained numerous computers, a flight simulator (ATC 610J), many books, most of my hand tools, and the nonfunctional remains of the ham radio equipment that I had used a decade earlier. It had been my intent to purchase new ham gear when the remodeling was complete. Another ham commented that many hams are active twice in their life, first as a teenager, and then as a retiree, and so it was to become with me.

In April of 2010, Margaret Guell, a friend from contra dancing, emailed to ask some questions about ham radio and suggested we go to Amateur

[1] J. C. Sprott, Microcomputer QSO Robot, *QST*, July 1981, pp. 30.

Electronic Supply in Milwaukee, one of the largest ham radio stores in the country, where they were having some kind of hamfest. She didn't buy anything, but I came back with a 100-watt ICOM IC-718 all-band transceiver, capable of code and voice communication using single sideband (SSB) modulation, which I had never used before.

Single sideband was already replacing amplitude modulation (AM) as the de facto standard for voice communication among hams as early as the 1950s, but it requires more sophisticated equipment beyond the construction capabilities of most hams, and I had always preferred using Morse code. SSB is a more efficient form of communication than AM, allowing lower power and narrower bandwidth, but it is not as efficient as Morse code. The whole transceiver was hardly larger or heavier than the tiny Davco receiver I had owned forty-five years earlier. It cost $600 and is considered at the low end of current technology. To make it more usable, I had to buy a narrow-band Morse code filter for $200 and an autotuner for another $150 to make it work on all bands with my antenna. This equipment was primitive by today's standards, but it was light years ahead of anything I had ever used before, and it was eventually replaced by an ICOM IC-7600 transceiver which cost almost $4000.



Me with the ICOM IC-718 transceiver I purchased in 2010.

Within a few weeks, I had the antenna back up between the trees and was


The ICOM IC-7600 transceiver I purchased in 2011.

on the air again. Although the long-range propagation conditions were only fair, I was able to contact almost everyone that I heard using either code or SSB. Not surprisingly, after being off the air for so long, many things were different and unfamiliar. In those two decades, cell phones, email, and the World Wide Web appeared. The world is a much smaller place than it was twenty years ago, not to mention fifty years ago when I began the hobby. The mystique of communicating with someone in real-time on another continent is long gone, but the idea that a hundred watts of power to a simple wire strung between the trees can reach that far seems as remarkable as ever, and it gives me a sense of awe to contemplate the physics involved when I stop and think about it.

My first reaction on returning to the air was that the bands seem deserted. Even when the propagation conditions should be good, I could tune across a whole band and hear nothing but noise. Perhaps there was a higher noise level with all the new electronic devices now in use, and the propagation conditions were poor since we were just coming out of a minimum of the eleven-year sunspot cycle, during which time long-distance communication is difficult. I suspect that the novelty of communicating over great distances is diminished, and many hams are now on the very high frequencies (VHF) where only local communication is usual or they are involved with other aspects of the hobby such as satellite and digital communications. One no longer has to demonstrate proficiency in Morse code to receive a ham license, and so I suspect the code activity will diminish as new hams join the ranks, replacing us old-timers. Mostly on the weekends when there are contests or when a station in a rare country appears on the air do I hear much activity on the high frequency (HF) bands.

Those using code seemed to be sending faster than in the past and making shorter transmissions. Although my ability to copy code seemed undiminished, I initially found it hard to send fast code with my electronic keyer as accurately as I once did, probably a result of being out of practice, or maybe my reactions have slowed a bit with age. I bought a memory keyer (HamGadgets MK-1) with an interface to the computer keyboard, but I rarely use the keyboard. I assume that Morse code is a slowly dying art and that it will eventually be sent and received only by machine, bringing an end to a golden era of radio communications when all hams possessed this skill and were suitably proud of it.

It is sometimes hard to understand the many new types of call letters that the stations are using, and the calls no longer guarantee their geographical district as in the past. There are even three-character calls for special events like W0L and W2W that never existed before, as well as some ridiculously long calls such as ZL4RUGBY and LZ1670SWS. Most people seem to be using the International phonetic alphabet (alpha, bravo, charlie, delta, ...) that I learned as a pilot rather than the old ones used in the military (able, baker, charlie, dog, ...) or just special or funny words they made up.

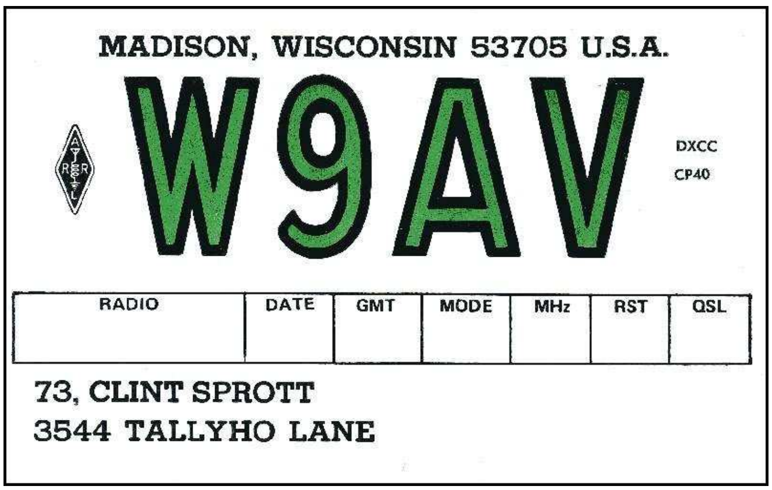
Perhaps the biggest change is that almost every station now has a computer at hand, either connected directly to the radio or just as an aid for logging and looking up information. The logbooks that were once required for every transmission are now optional, but most people seem to be using computer logs, and I downloaded one from N3FJP that turned out to be convenient and easy to use. This was after I had spent a month writing my own computer logging program and then losing it in a disk crash. I discovered that nearly everyone I hear on the air has a web page at QRZ.COM, and so I posted one there too.[2] It is fun to type in the call letters of the stations I talk to and see photos of them and their equipment and to read their short autobiographies, although it removes some of the mystery of talking to total strangers, bound together only by a common hobby. Perhaps it's a bit like the loss of imagination when television replaced radio in the middle of the last century.

The web pages provide some sense of what kinds of people are active hams. The average age of hams has risen from twenty-eight in 1960 to fifty in 2011. When I started, there were many teenagers as well as adults of all ages. Now I see very few young people and many older retirees. Their

[2]My ham radio web page is at http://www.qrz.com/db/W9AV.

stations are also neater and more sophisticated, not like the simple home-brew equipment buried in a maze of wires that most of us used fifty years ago, although I suppose the probably tidied things up before taking a photo to post on the Web.

They often have many more pieces of equipment and nearly always have a prominent computer, sometimes with multiple large monitors. The computers allow one to see real-time propagation conditions and predictions and to exchange QSLs on-line to confirm contact instead of the postcards we used to send by regular mail. I can even directly email the person if I wish. I was blown away by one ham's page that had a live webcam of him operating and to hear my transmissions over the air repeated back to me over the Internet with a few seconds delay.




My latest QSL card. These cards are exchanged in the mail by hams to confirm having made contact over the air as a way to qualify for various operating awards.

Contests in which hams contact as many others as possible within a limited period of time, usually on the weekends, seem as popular as ever. In fact there are many more such contests, and there are web pages that list them all.[3] Whereas there was one every couple of months when I started in the hobby, there are now several every weekend, although most are relatively small with limited participation. I notice more automation. Keeping computer logs eliminates the old problem of checking for multiple contacts with the same station in real time and simplifies the exchange of electronic

[3]The contest calendar I use is at http://www.hornucopia.com/contestcal/.

confirmation (QSL cards) and tracking progress toward the many operating awards. Many people obviously have recorded voice or code messages that they send at the press of a button, something I developed briefly using an old tape recorder many years ago before such technology was common and which I now use regularly.

There is a website where hams post notices when a rare country is on the air, and my log program allows me to click on their call, and it automatically tunes to receiver to their frequency. That made it possible for me to communicate with as many countries in a few months as it had taken me several years as a teenager, and many more countries now seem to have active hams with state-of-the-art equipment. I am still plagued by the large hill that rises just behind the north side of my house to well above the height of my antennas and the electrically noisy power line half way up the hill and barely fifty feet from my antennas. It turns out that most of the inhabited world is north of Wisconsin by the great circle, and so with the exception of Central and South America, the Caribbean, and most of the USA, it is a struggle to compete with hams running higher power to large rotatable antennas with a good view of the horizon in all directions.


My W9AV station in 2011.

A few other things have changed. There are now several new frequency bands for hams (called ‘WARC bands’), and they have a more complicated structure according to the type of communication (code or voice), power level, and the grade of license (novice, technician, general, advanced, extra). I used to send in code ‘name is Clint,’ but it seems that one is now supposed to say ‘op Clint,’ which means ‘operator is Clint’ and is a slight saving of time in today’s fast-paced world. When calling another station, one used to send their call (sometimes several times) followed by ‘de’ (from) and then one’s own call letters (sometimes several times). Now with transceivers that can tune the frequency with an accuracy of just a few kHZ, it seems usual to call another station by just sending your own call once or at most twice. There are new terms for old concepts like ‘running’ and ‘spot and pounce.’ When rare stations appear on the air, the pileups of people trying to contact them seem larger and more disorderly, and rarely am I able to hear the station everyone is calling even by tuning to nearby frequencies. Apparently my antenna and its height are not up to current standards as evidenced by the photos I see of other stations on the Web, but I am having fun rekindling some of the enjoyment that I had as a teenager and reliving some of the experiences that led me to a career in physics.

# Chapter 22

# Celebrating at Seventy

Time sneaks up on you like a windshield on a bug. –Jon Lithgow

On July 1, 2012, my wife and I attended a small dinner party to celebrate Robin Chapman's birthday. That planted the idea in my wife's head of having a similar party to celebrate my seventieth birthday on September 16, 2012 and to show appreciation of our friends and reciprocate for their past invitations. Initially I was resistant to the idea, and only found out a week or two in advance that she had invited eleven of my close friends for dinner and celebration. Thinking of spending an evening with this group, all of whom I greatly enjoy, suddenly seemed like a fine idea.

The invitees included Robin and her husband Will Zarwell, Myrna Casebolt and her partner (and later spouse) Jayne Grant, Marjorie and Boris Matthews, Cassie Kight and her (now ex-) husband Steve Bray, Mary Hegge, and Dale Konle and his partner Kim Miller. Everyone accepted the invitation except Dale and Kim who were dealing with a family health issue and numerous visiting relatives. Many others could have and perhaps should have been invited, but Dan wanted to keep the group small, and she knew I had a special fondness for these people as does she.

Dan spent most of the weekend planning and preparing a fine dinner, and I helped clean and ready the house and yard for their 4:30 pm Sunday arrival. After dinner, but before the obligatory birthday cake, I made a few brief remarks. What follows is a condensed written version of what I said, or rather what I would have said if I had been more articulate.

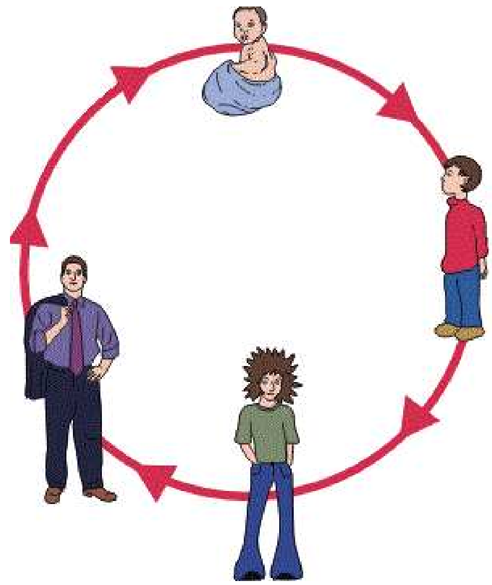
* * *

Attendees at my seventieth-year birthday party. Left to right: Mary Hegge, Cassie Kight, Steve Bray, Boris Matthews, Jayne Grant, Myrna Casebolt, Robin Chapman, Morjorie Matthews, and Will Zarwell.

I want to welcome you to this celebration of my seventieth birthday and share a few thoughts with you. I've done this in the form of a PowerPoint presentation since that's the mode to which I've become accustomed in my academic career. Like many professors, I have an internal clock that dictates a presentation of precisely fifty minutes, but I'll attempt to be brief. In fact, I have only three slides. I had four more, but they were densely filled with equations, and so out of consideration for Myrna and others, I deleted them.

The starting point for any talk or paper is to choose a title, after which everything else flows easily, and I've chosen 'Cyclic Dynamics in Relentless Aging.' By cyclic, I do not mean that one is born, matures, and then reproduces, but rather that we regain some of our childhood characteristics as we grow old instead of progressing along a straight line beginning at birth and ending at death. I want to give three examples of such cyclic dynamics.

I must have been about seven years old when I had my last birthday party. I remember we played 'Pin the Tail on the Donkey,' and perhaps we



Cyclic Dynamics in Relentless Aging.

can do that again before the evening is over. I've always thought that our sense of time, like our sense of sight and hearing, is logarithmic, by which I mean that a decade seems to go by as quickly at age seventy as a year does at age seven. Thus it's appropriate that Dan says my next birthday party will be in twenty years, after which they will be every ten years. Probably the time will come when I celebrate every year, just as I did for the first few years of life.

But the first example of cyclic dynamics is **forgetfulness**. They say there are two signs you're getting old. One is that you forget things, and for the life of me, I can't remember the other.

When I was a child, my mother had to remind me to put on my coat before I left for school. Eventually, I became more responsible, but as I get older, I'm becoming more forgetful again. Actually, I've always had a bad memory and have particular difficulty with people's names and faces, but I'm confident that I know all your names and would recognize you instantly in a crowd, as I'll demonstrate shortly.

One of the reasons I went into physics is that it requires very little memorization, in contrast to biology, which is replete with names. Unlike Robin and others, I never learned the names of many trees, birds, and flowers. Fortunately, scientists and professors are expected to be somewhat absentminded and a bit eccentric, and I've attempted to project that image throughout my entire career. Have you ever wondered why professors like to use PowerPoint presentations? It's not primarily for the benefit of the audience as you might assume, but rather to keep themselves on track and moving along at a reasonable pace instead of wandering off on a tangent as I seem now to be doing.

The second example is **food**. When I was a baby, like most of you, I'd cry when I was hungry. Eventually I learned not to do that and even developed some primitive cooking skills, although for most of my life I was content to at least occasionally drink a can of Hershey's Syrup and call it dinner. As a way of simplifying my life, I long ago broke the habit of eating lunch.

This past Tuesday, I walked into the noon Chaos and Complex Systems Seminar and was immediately greeted by Will with an apology for not bringing me any food. Then Robin offered me a cookie, which I declined. As I sat down, my visiting Chinese scholar Chunbiao Li came in the door and said he had just been at Union South and brought me a slice of pizza, which he left in my office. I thanked him and told him he didn't need to do that. Moments later, Wayne Lasek walks in the door and hands me a sausage sandwich. With all the talk about food, I was starting to get hungry, and so I ate the sandwich and subsequently the slice of pizza, which was fortunate because Dan worked late that day and didn't get home until I had left for the contra dance, after which I finished off the day with a dish of chocolate ice cream in the company of a congenial group of dancers.

But it got me wondering if for the rest of my life everyone will be assuming that I'm incapable of feeding myself. That day may come, but for the present, my food science wife is more than capable of keeping me well fed and nourished, although I've also had an influence on her since she now likes to share my can of Hershey's Syrup.

The third example of cyclic dynamics is **friendships**. When I was a child, I had friends with whom I played, and I continued to have friends throughout college. But once I entered graduate school and married, I decided that I didn't need any friends and that my passion for physics would suffice. It was not so much a conscious decision as it was a matter of getting caught up in my research and a degree of social isolation and awkwardness that made it difficult for me to make new friends.

A decade later, I was divorced and had a succession of dating relationships for the next two decades but still no close friends. This was despite the fact that I was an avid dancer, including folk dancing, square dancing, and contra dancing, all of which are social dance forms. I never really got to know any of the people with whom I danced.

A turning point occurred about twenty years ago, and I credit that largely to Marjorie who encouraged the dancers to go out for ice cream after the contra dances. She also organized other outings for us including some parties at my house, which I had never had before. I gradually got to know some of the people I had been dancing with, and now my closest friends are those I met dancing.

It was a result of those visits to the ice cream shop that I got to know Robin much better since she used to leave her car at Gates of Heaven and carpool with me to Michael's East for ice cream. This was long before she and Will became a couple, although the three of us knew one another from our occasional interactions at dances and other events over the years.

Robin was the first of my new friends to get married. Although she and Will have been married now for over a decade, they still act like newlyweds. As I've said to Will many times, he really spoiled it for the rest of us because now all the women want a mate just like him, and the rest of us can't possibly live up to that standard.

Marjorie and Boris got married about the same time, and I was an usher at their wedding and made a rather unusual toast to them that they still seem to remember. It was something about a chicken and a duck. I should remark that Boris has been around the block a few times, and I suspect he agrees with my theory that we return to our childhood as we age. Thanks, Boris, for staying up past your bedtime to attend my birthday party!

About ten years ago, my Swiss girlfriend Janine affectionately commented that in many ways I remind her of a ten-year-old, but that I shouldn't worry because I was several years ahead of Dale, of whom she was also very fond. It made me wonder why Dale and I, who are different in many other ways, have this in common, and I concluded that it was probably because neither of us ever had children, and so we never had to completely grow up and become responsible adults. In any case, I'm pleased that I share this characteristic with Dale since I've always admired his youthful attitudes and playfulness.

Dale and I have another characteristic in common as Robin pointed out to him when they were with a group on a canoe trip. She told him that he and I are like moose. Now Dale is an intelligent guy, but he can sometimes be slow to catch on to things. You'd think he would ask Robin what she meant, but he didn't. A week later, he and Janine and I were walking in the Arboretum, and he mentioned to me Robin's comment and asked what

I thought she meant. I had no idea, but knowing Robin, I assumed it was a compliment. Perhaps we were King of the Woods or something. When I next saw Robin, I asked her about it, and she said that we both liked to be surrounded by attractive young females, a fact that I cannot deny.

There's a bit more to the moose story. Shortly after that, Janine and I were in Door County and saw a tee-shirt in a gift shop with a large picture of a moose on it. She suggested I buy it and wear it to the next contra dance to amuse Dale. I was hesitant until she offered to wear her funny tee-shirt with a large picture of a fish on it. At the dance we went up and down the line with many people commenting on our shirts, but we could not get Dale to notice. About that time, Robin and Will arrived at the dance, fashionably late as is their custom, and from across the room, Robin spots my shirt and breaks out laughing.

Then I had the idea that when we get to the end of the contra line, Janine and I would dash out of the room and change shirts and then get back into the line just in time to continue dancing. Surely Dale would notice then! Up and down the line we went with everyone laughing and commenting except for Dale, who still didn't notice. Finally, Emilie Grossmann, who was Janine's office mate and with whom Dale was dancing, whispered in his ear 'Dale, they traded shirts.' I wish I had a video of the look on his face when he finally noticed the moose. It was also a coming out for me and Janine since most people didn't know we were dating, apparently including Dale, which explains how the three of us happened to be walking together in the Arboretum.

Speaking of young, attractive females, I want to mention Mary. She is someone I would have never gotten to know until recently because we are both slightly shy. In fact, our paths crossed a number of times at dances in the distant past, but I don't think we ever spoke until about three or four years ago when she started contra dancing again and I was adequately socialized. She is a more recent friend than many of you, but her quiet charm and pleasant nature always delights me.

What Marjorie did for the dance community, Myrna did for the Chaos and Complex Systems Seminar about a decade ago. For the first few years, people attended the seminars and then went their separate ways when the talks ended. Myrna wanted us to get better acquainted, and we started meeting for lunch on the Union Terrace every Tuesday during the summer. She has always contended that many of society's problems could be solved if we would just sit at the table together and discuss our differences, and that's

Dale Konle, Emilie Grossmann, me, and Janine in August 2001.

literally what we've done on a small scale for over a decade. Those lunches are a highlight of my week, and I look forward to the coming of summer every year and resuming our stimulating discussions. I wish that Jayne would find the time to join us so that we could get better acquainted with her.[1]

Cassie and I have known one another for about twenty years and have been through a lot together. We met at a Scandinavian dance shortly after she came to Madison from Berkeley, but she became an active contra dancer and caller for many years. What you may not know is that she did much of the shopping with me for clothes, luggage, and even helped me select a car. I've worked hard over the years at projecting an image of childish helplessness, which has served me well, especially in the presence of nourishing females. We always spoke of growing old together, and joked about having a car that would accommodate her if she ever became disabled.

Cassie is the most recent of my friends to get married, and Dan and I attended her and Steve's wedding in Peoria about three years ago. Perhaps that helped to plant in Dan's mind the idea that we should also get married. If Steve can manage to stay out of jail, I'm sure they will have a long and happy life together.[2]

[1]Unfortunately, Jayne, who is two years my junior, died unexpectedly on June 12, 2015 while vacationing in Europe with Myrna.

[2]Two years later, Cassie and Steve decided to divorce.

Cassie and me with others at my birthday party in September 2012.

I am blessed to have a number of close friends at this stage in my life, and I thank you for your friendship and for taking the time to join me in this celebration of my seventieth birthday. Let do it again in twenty years!

# Chapter 23

# Lessons in Chaos and Complexity

> When we try to pick out anything by itself, we find it hitched to everything else in the Universe. –John Muir

On May 7, 2013, I gave a talk in the Chaos and Complex Systems Seminar, a condensed version of which follows:

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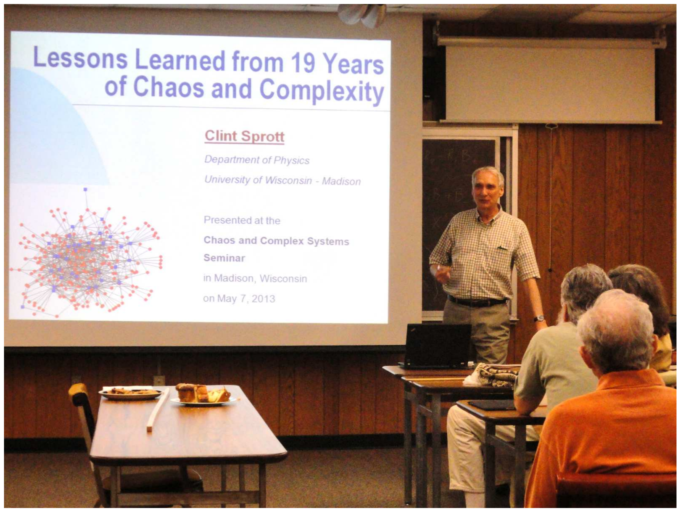
It seemed to me that after 19 years and almost 600 talks in this seminar series, someone should summarize what we've learned. Since I've probably heard more of the talks than anyone else, I decided to give it a try. It's my hope that this will become a tradition, with others of you sharing what you have learned, and it could also provide a framework for our summer discussions on the Union Terrace.

In this talk I'll describe the different approaches researchers have taken to understanding the world, make some general observations about the prospects and limitations of their methods, and share some of my views about the future of humanity. It will necessarily be personal and somewhat subjective, and thus probably controversial.

Either explicitly or implicitly, most people, both scientists and non-scientists, are trying to understand the world by making models. Some people have a model in which events are determined by God or perhaps by the position of the planets at the moment of one's birth. A model is a simplified description



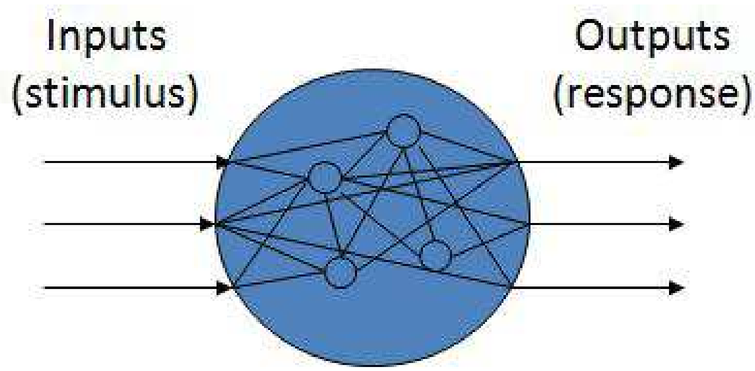

A talk I gave at the end of the 19th year of the Chaos and Complex System Seminar on May 7, 2013.

of a complicated process, ideally amenable to mathematical analysis. However, as the late George Box reminded us, 'all models are wrong, but some are useful.' Furthermore, the usefulness of a model may not relate to how realistic it is. A simple model is usually more informative and sometimes more predictive than one that includes every effect that one can imagine.

Typically a model involves one or more agents. Although 'agent' suggests a person, it could also be a whole society, an industry, an organism, a neuron, or even an individual atom. Agents are exposed to stimuli and exhibit corresponding responses. Sometimes we know the stimuli and are trying to determine the response; other times we observe an action and seek to understand its cause. Science could be defined as the study of such cause-effect relationships.

Consider an example. Somewhere I read that people who floss every day live six years longer than those who don't. The flossing is the stimulus, and the increased longevity is the response. The agent could be an individual, or it could be a statistical statement about a whole society.

In fields like physics, we have the luxury of going into the laboratory and doing a controlled experiment on the agent. Even psychologists experiment with human subjects, but more often, when the agent is something like a galaxy, a society, or an economy, the best one can do is to make observations, attempting to correlate stimuli with responses. The difficulties are a paucity




Science is the study of cause-effect relationships for agents, whose internal workings usually involve other agents.

of data, a lack of adequate control, and the inability to distinguish correlation from causality. Those who floss are probably also engaging in other healthy activities.

A third approach is to use reductionism, in which one looks at the inner workings of the agent, where other simpler agents are found, and then try to develop a theory relating the response to the stimulus. Scientists are sometimes attacked for their theories by people who equate ‘theory’ with “speculation” and who instead want to know the ‘facts.’ However, theories are much better than facts, since they provide understanding and prediction even outside the realm where they have been tested. If we had a theory for why flossing increases longevity, it might suggest alternate ways to achieve the same or even better result.

By the way, there is no such thing as ‘chaos theory.’ Chaos is something that occurs in dynamical systems for which there is a theory. It’s like talking about the ‘theory of falling.’ We can describe falling and even cite its rate on different planets, but there is no understanding or predictability outside the realm of where it has been found to occur apart from the theory of gravity that does predict the phenomenon even in places where no experiment on falling has ever been performed.

I’m glad there are people willing to devote their whole professional career to looking for the Higgs boson or understanding the nervous system of a worm. Reductionism has been a powerful scientific method, but it takes enormous patience, perseverance, and financial and human resources. Furthermore, even a complete understanding of the inner workings of an agent may not shed much light on the emergent behavior of the agent because of the multiple levels of complexity.

A common difficulty is that responses sometimes occur in the absence of any apparent cause, and there are many reasons for such nonstationarity. The agent may be remembering some event in the past, or perhaps the causes are not adequately identified or controlled, or there is noise or measurement error. However, even in a perfect experiment, the agent can exhibit a time-varying behavior due to some internal dynamic even when all the external stimuli are constant—a common occurrence to which I will return shortly.

The simplest cause-effect relationship is linearity. Linearity does not mean a chain of causality in which A causes B which causes C, and so forth, but rather that the response is proportional to the stimulus. In the flossing example, it means that I would gain about one year of life by flossing weekly, or sixty years by flossing ten times a day. If I accepted the fact about flossing and believed in a linear model, I'd probably be flossing right now.

Furthermore, linearity means that the response to two or more stimuli is the sum of the responses to each individually. Doctor Öz[1] claims that those who have 200 orgasms a year live six years longer, which sounds like more fun than all that flossing. Now maybe he means that to be an optimum, and some of you need to cut back, but my point is that linearity says that I could gain twelve years by appropriately manipulating two parts of my anatomy. Of course, Dr. Öz also says we live one hour longer for every hour we spend walking, which means I could be immortal if I got moving, and it makes you wonder how much Dr. Öz really knows about orgasms.

If linear models make such nonsensical predictions, why would one even consider them? First of all, they are simple and provide a good starting point. Secondly, it turns out that most things are linear if the stimulus is sufficiently small. Finally, linear systems of equations can be solved exactly and unambiguously for any number of variables, although, as a practical matter, a computer may be required if the system is large.

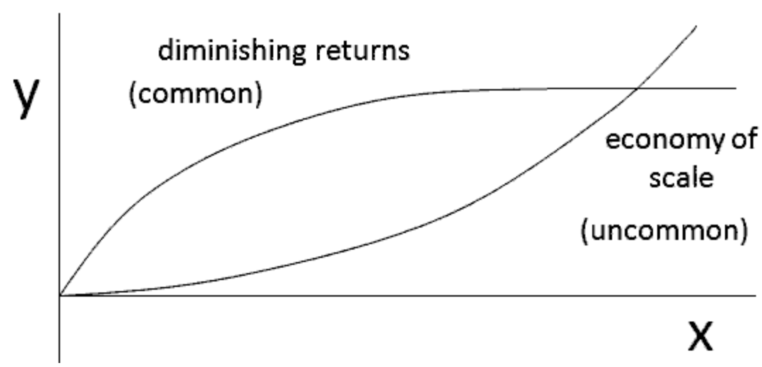
It often happens that an agent is stimulated by its own response in a feedback loop, either directly or indirectly through other agents. Thus the effect becomes the cause, and the cause becomes the effect, like the chicken and the egg. The feedback can be either positive (reinforcing the response) or negative (inhibiting it). In such a case, time-varying dynamics can occur

[1] Dr. Mehmet Öz is an American-Turkish cardiothoracic surgeon, author, and television personality.

because of the inevitable time delay around the loop, and that time delay determines the time scale for the dynamics.

In a linear system with feedback, only four things can happen. Negative feedback leads to exponential decay or a decaying oscillation, while positive feedback leads to exponential growth or a growing oscillation. Positive feedback implies a source of energy or other resource from outside the system. A PA system exhibiting audio feedback will go silent if the power is removed. These four linear behaviors are rarely seen, especially unlimited exponential growth, because resources are limited and nature is not linear.

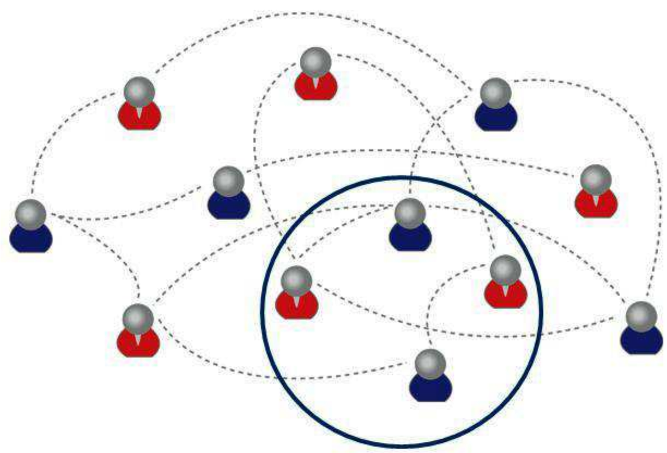
There are many possible nonlinearities. In two simple examples, the response increases monotonically with the stimulus but either slower than linear (diminishing returns) or faster than linear (economy of scale). An example of a mathematical function that is slower than linear is the square root, and one that is faster than linear is the square. I would argue that the former is more common since the response usually cannot increase without bound. Even if I could gain six years by flossing daily, it's unlikely that I could gain 144 years by flossing hourly or by having 13 orgasms a day. As Joel Robbin reminded us, 'too much of anything is bad; otherwise it wouldn't be too much.'




Two simple examples of nonlinearities, one slower than linear and the other faster than linear.

Nonlinear agents with feedback can exhibit a wide variety of dynamics including the four linear behaviors already mentioned. They can have multiple stable equilibria. They can have stable periodic cycles. They can exhibit quasiperiodicty, which means a combination of periods. They can have bifurcations in which a small change in a parameter causes a completely different dynamic – what Al Gore calls a 'tipping point.' They can exhibit hysteresis, a form of memory in which the original behavior cannot be recovered after a bifurcation without making a large change in the opposite direction. They can have coexisting (or hidden) attractors, meaning that different dynamics are possible even for a given set of conditions, depending on the past history of the system. And, of course, they can exhibit chaos in which a small change in the initial condition completely changes the future.

Most systems in the real world involve large networks of nonlinearly interacting agents. The ecological system, the climate system, the political system, and the economic system each involve numerous agents and are strongly coupled to one another. Of necessity, most scientists are studying a small part of a much larger network, hoping that the part not being studied can be treated as a fixed external stimulus. I think this often leads to erroneous conclusions and predictions, as does the implicit assumption of linearity and the disregard of feedback loops.



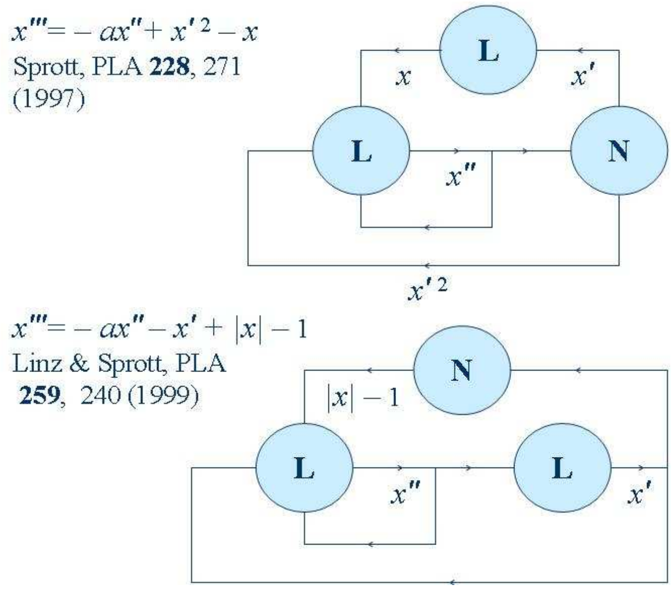
Most scientists, of necessity, are studying a small part of a much larger network, hoping that the part not being studied can be treated as a fixed external stimulus, often leading to erroneous conclusions and predictions.

For example, if some species of animal consumes some species of plant as its primary food supply, and the abundance of that plant is suddenly reduced to half, we might naively assume that half the animals would die. However, it is much more likely that they would find a different source of food somewhere. Similarly, if global warming causes the sea level to rise a meter over the next century, it's unlikely that the hundred million people who now live along the coast will drown as a result, and much more likely that they (or rather their descendants) will simply migrate to higher ground, or perhaps they will build some simple dikes as the Dutch have done.

An alternate approach is to characterize the general behaviors of large nonlinear networks without regard to what they are modeling. This is an extension of the method used by mathematicians to characterize the nonlinear dynamics of simple systems. The task is made difficult (and interesting) by the fact that the architecture of a network (the connection strengths between the agents) can change in time even while the network is exhibiting dynamics, and the two types of dynamics are coupled. This distinction is sometimes called the dynamics OF the network as opposed to the dynamics ON the network. The neurons in the brain slowly reconnect even while the brain is actively performing tasks and in response to those activities. Curiously, an evolving network can always be exactly represented by a (sometimes much) larger network with static connections. What we need is a set of laws governing the behavior of large networks analogous to the laws of thermodynamics that describe the behavior of gases without the necessity of knowing what the individual molecules are doing or why or even that the gas is made up of molecules.

If I may digress for a moment, I would like to mention one accomplishment of which I'm especially proud. Twenty years ago, I became interested in the question of what is the simplest network that is capable of exhibiting chaos. One would think that question had long ago been asked and answered, but apparently not. I didn't originally think of the question in that way, but rather I was trying to find the simplest ordinary differential equation whose solution is chaotic, and it was only in preparing this lecture that I realized it was the same question. It has long been known that at least three agents are required and that at least one of them must be nonlinear, but I was able to show that only three feedback loops are required and how they are arranged. Two years later Stefan Linz and I found another equally simple arrangement, and both cases were published in Physics Letters A.

Large nonlinear networks are appropriate models of complex adaptive systems of the type that occur throughout nature, and much has been learned recently about their behavior. In particular, they are usually chaotic, although only weakly so, and thus they are inherently unpredictable but sensitive to small changes in both the state of the system and the parameters, and thus potentially easily controllable. More interestingly, such systems can self-organize, adapt, and learn—qualities we normally associate with human intelligence, but that are observed in physical systems as well. Witness the




The simplest nonlinear networks that are capable of exhibiting chaos.

organization of the Universe into galaxies and stars and planets that ultimate gave rise to life on Earth.

We have heard many speakers over the years make dire predictions, especially regarding the climate, the economy, and the ecology, but I am more optimistic than most about our future for five fundamental reasons:

1) Negative feedback is at least as common as positive feedback, and it tends to regulate many processes.

2) Most nonlinearities are beneficial, putting inherent limits on the growth of deleterious effects.

3) Complex dynamical systems self-organize to optimize their fitness.

4) Chaotic systems are sensitive to small changes, making prediction difficult, but facilitating control.

5) Our knowledge and technology will continue to advance, meaning that new solutions to problems will be developed as they are needed or, more likely, soon thereafter in response to the need.

Whether it's fusion reactors, geoengineering, vastly improved batteries, self-driving care, halting of the aging process, memory implants, de-extinction, or some other game changer, things may get worse before they get better, but humans are enormously ingenious and adaptable and will rise to the challenge of averting disaster.

This is not a prediction that our problems will vanish or an argument for ignoring them. On the contrary, our choices and actions are the means by which society will reorganize to become even better in the decades to follow, albeit surely not a Utopia.

# Chapter 24

# Travels

> Thanks to the Interstate Highway System, it is now possible to travel from coast to coast without seeing anything. –Charles Kuralt

Some people like to travel, considering it a great educational adventure. I'm not one of them. I once enjoyed flying, but that pleasure is now diminished by the new security measures, crowded planes, flight delays, additional fees, and loss of amenities. It's stressful to be away from home, especially alone, and to deal with the issues of transportation, meals, tipping, and sleeping in a strange bed. It's hard to be away from my computers, radios, bicycle, magazines, local newspaper, as well as my friends and significant other.

When I was young, our family took month-long automobile trips most summers, usually staying in a different motel every day along the way. That was before interstate highways, and so progress was slow, and my father did all the driving except when my older brother accompanied us. By the time I was in high school, I had visited all but two of the forty-eight states (Alaska and Hawaii were not states until 1959) and most of the national parks and other major tourist attractions. I tolerated those trips reasonably well and benefitted from the experience, but it was not something I relished, and returning home was always a relief. Those were all domestic trips except for brief excursions into Canada and Mexico.

We had a cottage on a lake in Mississippi a two and a half hour drive from home that we sometimes visited on weekends. At first that was fun, but eventually it became boring since my parents liked to fish and hunt for Indian arrowheads along the beach, for which I had little patience or tolerance. They would let me take along friends for company, including girlfriends as I got older, and that kept me entertained. They sold the cottage after I left for college.

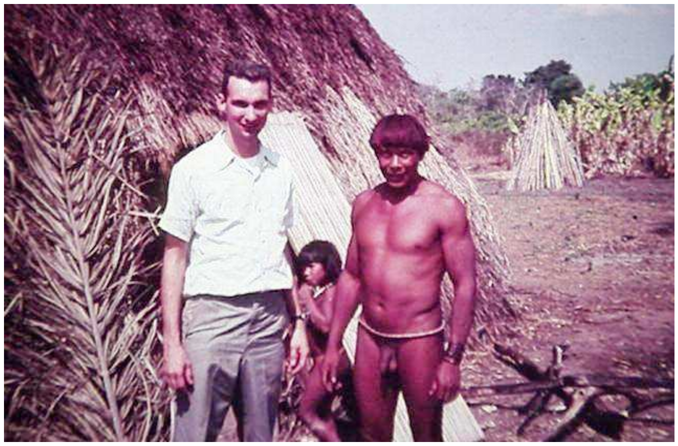
Attending college at MIT was the first time away from my parents, and it was a life-changing experience to which an earlier chapter was devoted. My first flight on a commercial airliner was returning to Memphis for Christmas during my freshman year. The Boeing 707 had recently begun service and ushered in the jet age. That was an era when flying was a formal event for which even the rare teenage passengers donned a suit and tie, and in-flight meals were served with cloth napkins and metal silverware by pretty young female stewardesses wearing caps and white gloves. I quickly adapted to air travel and made trips back to Memphis twice a year during college.

The summer after my sophomore year was spent at the headquarters of The Navigators in Colorado Springs, but I seldom ventured far from their site at Glen Eyrie, the former estate of General William Jackson Palmer, the founder of Colorado Springs, which included a 67-room castle. I did occasionally walk over to the Garden of the Gods and to Williams Canyon, with its Cave of the Winds, both of which are popular tourist attractions. During that summer, I also made the first of two treks to the summit of Pikes Peak.

The summer after my junior year in college was spent traveling around Brazil visiting missionaries, including a week-long visit to primitive Indian tribes deep in the interior in a Helio Courier, a small four-seat plane designed for landing on small jungle airstrips. At the time, there were few highways in Brazil, and most travel was on old DC-3 and sometimes DC-6 airplanes. This was surely my greatest travel adventure, and it happened at the young age of twenty. On one occasion, the pilot invited me into the cockpit as he descended to treetop level so that we could look for monkeys while winding our way up the Amazon to Manaus.

On the next flight from Manaus to Brazilia over dense jungle and hours from civilization, one of the engines quit on our DC-6. It was such a common occurrence that they didn't even illuminate the seat-belt lights or make an announcement. I might have slept through the whole thing had I not awoken to see one of the four propellers windmilling out the right side window. On the way back to the USA, I spent a few days in Lima, Peru.

Once I began graduate school in Madison, there were more opportunities to travel, mostly to domestic scientific conferences. In November of 1965, I



Me with primitive Brazilian Indians in 1963.

attended my first annual meeting of the Division of Plasma Physics of the American Physical Society, and every following year for the next forty-two years. That took me for a week to most major cities in the country, although I usually saw little more than the airport and the hotel and its immediate surroundings. Occasionally, I would go by car when the meeting was in Chicago or Minneapolis, and during the 1970's, I would often pilot a small planeload of students and faculty, but most of the trips were on the airlines.

After getting a PhD in 1969, I went on interview trips to General Atomics in San Diego, Sandia National Lab in Albuquerque, Lawrence-Livermore National Lab near San Francisco, and Oak Ridge National Lab near Knoxville, whose job offer I accepted. I spent the next two years in Oak Ridge, and it was there that I took up flying, which offered more reason to travel as described in an earlier chapter. I flew to most major cities east of the Rockies, and as far west as Albuquerque, as well as to the Bahamas.

In 1972, I returned to Madison, first as a visiting professor and then a year later as a tenure-track assistant professor, and there were many opportunities to travel to conferences and to serve on scientific review panels. I think it was 1975 when I attended my first international conference. It was the first time I had been to Europe, and I took a few extra days to visit Italy, Switzerland, and Germany with Melanie. That was when I decided that international travel was even more stressful than domestic travel with the added difficulties of language, currency, and unfamiliar customs.

I tried to avoid foreign travel after that, preferring to ask others to attend the scientific meetings even after I became the principal investigator of the

Plasma Group. However, I could not avoid all such travel, and I went to Japan five times, as well as France, Germany, and England. The Japanese were doing plasma work closely related to ours, and I was appointed to a Department of Energy committee to plan Japanese–American scientific exchanges.

In the late 1970's, I consulted with McDonnell Douglas in Saint Louis for three years, spending one day a week commuting by airline. It became a routine and a welcome break from my faculty job at the University in Madison, but I disliked those occasions when I had to spend the night in Saint Louis or when the flights were delayed or crowded. That was an era when smoking was allowed in the rear of the plane, and I sometimes found myself seated in the smoking section, which was especially unpleasant. I bought a lifetime membership in the American Airlines Admiral's Club for $300 and wrote major portions of my first book on the airplanes and in the Chicago O'Hare Admiral's Club between flights.

One memorable experience was when I had a chance to fly to Washington, DC in their McDonnell Douglas company Learjet to defend a proposal for a bumpy torus they had written for the Department of Energy. The pilots knew that I was a relatively new private pilot, and they let me sit where I could watch the instruments and see out the front as we cruised at 45,000 feet, the highest I have ever been above the ground. I also took consulting trips for Oak Ridge National Lab (Oak Ridge, TN), TRW (Redondo Beach, CA), Argonne National Lab (Chicago), Honeywell (Minneapolis), Saunders College Publishing (Philadelphia), and the Chicago Museum of Science and Industry, among others.

I traveled relatively little in the 1990's because I was no longer active in plasma physics and had not yet developed a reputation in my new field of Chaos. I had no funding for travel, which was fine since I didn't enjoy it anyway. I still attended the yearly Division of Plasma Physics meetings and perhaps one other conference every year, and what vacations I took were usually spent somewhere within driving distance. I especially enjoyed camping on the shores of Lake Superior, but those trips were just long weekends. I was very much a homebody.

Around the turn of the Millennium, I began to travel a bit more for both business and pleasure. Marsha convinced me to take week-long vacation trips to Huatulco, Mexico and Banff National Park in the Canadian Rockies. It felt odd to pay for an airline ticket, since nearly all of my previous trips had been paid by someone else.

Janine invited me to Switzerland on three occasions totalling about three months, and she made those trips especially enjoyable, although I worked much of the time writing my first chaos book. We made side trips to Germany, England, and Italy where we visited friends and I gave talks about my research. During the two years that Dan was at the University of Minnesota, I visited her every other weekend, usually for three days. These were partly working trips, but I got to know the Twin Cities through our many outings there.

By the late 1990s, I was becoming established in my new field of research, and as a result I began getting requests to give invited lectures and seminars, which I generally agreed to do if they paid all my expenses. Such trips were more pleasurable than the conferences I previously attended since the host usually treated me well, sometimes to the point of exhaustion, and I felt a sense of importance that was lacking earlier in my career. Even so, I tried to keep the trips short and focused on the purpose at hand. I was selected as a distinguished lecturer for the Division of Plasma Physics of the American Physical Society during 2011–2013, and that resulted in trips to Salt Lake City, UT, Daytona Beach, FL, Carlyle, PA, and Washington, DC.

About the same time, *The Wonders of Physics* was gaining an international reputation partly as a result of its exposure on the Web. I got numerous invitations to make the presentation in remote locations. Usually, I would hand off such requests to our outreach coordinator, whose job it is to do that, although I made some domestic presentations myself in Fairfield (CT), New Orleans (LA), Billings (MT), and Cheyenne (WY), for which I would fly to the location while our outreach coordinator would transport the equipment by truck and set it up for me. Most of the requests from abroad were withdrawn once they realized the complexity and cost that would be involved. However, I did presentations of *The Wonders of Physics* in Portugal, Egypt, and Japan using equipment that they provided.

The first of these international trips was in 2006 to Portugal. It was an experiment to see if we could manage in a foreign land with unfamiliar equipment, and I took Jim Reardon along to assist. It went well, and that encouraged me to try again under similar conditions. It was also a nice source of added funds for *The Wonders of Physics*.

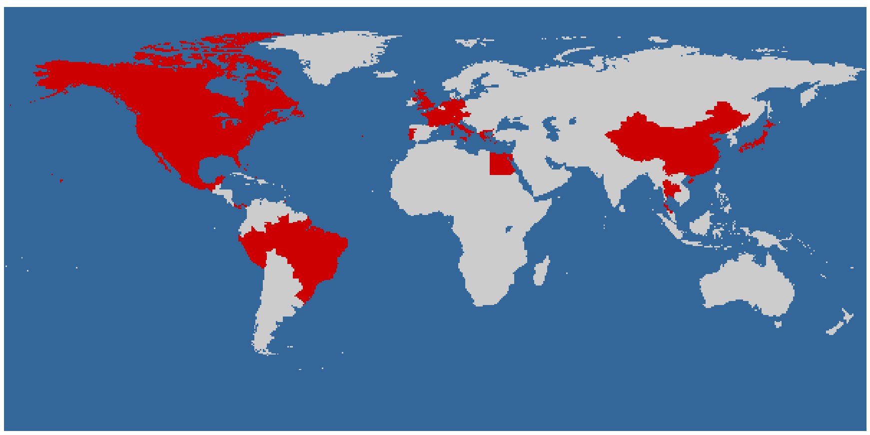
In 2011, I went to Egypt to make two presentations of *The Wonders of Physics* at the American University in Cairo, along with two technical talks. This was just a few months after the ousting of President Hosni Mubarak, and the country was in a state of mostly peaceful turmoil, although several protesters were killed during my week there. One of my presentations was just a few blocks off Tahrir Square, the center of the demonstrations, and my hotel was sufficiently close that I could walk down to the Square to observe the demonstrations, which I did.


Arriving at the American University in Cairo in 2011, I found kiosks around the campus advertising my public lecture.

Several months later, I was off to Japan to appear on Nippon TV doing physics demonstrations in competition with a Japanese counterpart with royal treatment and generous compensation including expenses paid for Dan to accompany me. During the same time period, I accepted invitations to travel abroad to give invited technical talks, in China (twice), Crete, Thailand, Hong Kong, and Sicily as a result of previous international collaborations. Only in 2012 did I visit Hawaii for the first time, completing my tour of all fifty states. Now I am collecting photos of state and national capitol buildings that I have visited.

The trip to Thailand in 2011 will always be remembered because only ten days before departing, I slipped on the ice at the end of my driveway and broke two ribs. I had never broken a bone before, and this is a particularly difficult and painful injury. There is nothing the doctors can do except to prescribe pain medication, which seemed to provide little relief. The only comfortable position was sitting upright in a chair, and I spent many nights sleeping that way. Somehow, I managed to give four lectures during that trip. I was in constant pain for six weeks, and it took about two months before things returned to normal.

In summary, I have lived in relatively few places. Except for summers, my geographical trajectory is simply Memphis (TN) → Cambridge (MA) → Madison (WI) → Oak Ridge (TN) → Madison (WI) where I intend to spend my remaining years. However, I have had ample opportunity to travel both domestically and internationally, although only in Brazil and Switzerland did I really much sample the local culture. There are not many additional places I would like to visit. Australia and New Zealand have a weak attraction as does any exotic tropical island in the Caribbean or Pacific, especially if I could carry and operate my ham radio. Meanwhile, talking to people in these exotic locations by radio is a reasonable substitute.



Countries I have visited.

# Chapter 25

# Extraterrestrials & Future Technology

> Two possibilities exist: either we are alone in the universe or we are not. Both are equally terrifying. —Arthur C. Clarke

> A linear projection into the future of any science or technology is like a form of propaganda—often persuasive, almost always wrong. —Pamela McCorduck (McCorduck's law)

The southern shore of Lake Superior has always been a special place for me. Of the dozen times I've been there, each trip has been different, depending on the companionship, the weather, and what was on my mind. The waves of crystal clear water lapping onto the sandy beaches, the rugged hiking trails through dense forests and along the colorful sandstone bluffs that give Pictured Rocks its name, the otherworldly expanses of sand dunes, and the ease of finding total solitude provide a welcome respite from the hurried and regimented life of the city and offer a good place to think. Although it's an experience best shared with someone special, on those few occasions when I went alone, it was a time to contemplate the big issues of life.

As I looked down at the sand that stretches for miles along the deserted beach during one visit in June of 2009, I was captivated by the thought that there are more stars in the visible Universe (about $10^{23}$) than grains of sand on all the beaches and deserts of the Earth. As I contemplated that, over 300 exoplanets had been discovered in our galaxy alone with more being discovered at a rapid rate, and so it is inconceivable to me that the only life in the Universe would be here on Earth. Of course it does not make sense to

Hiking along Twelve-Mile Beach at Pictured Rocks National Lakeshore on Lake Superior.

calculate probabilities based on a single observation. After all, the probability that I would be sitting there contemplating that was essentially zero, and yet there I was. That's why the discovery of any form of life elsewhere in the Solar System, perhaps on Mars or on one of the moons of Jupiter or Saturn, would be of monumental importance. Assuming it developed independently and was not of a common origin as life on Earth, that would mean that life almost surely exists in countless places throughout the Universe.

In nearly every case, such life must be either vastly more primitive than humans or vastly more advanced. In the few billion years that life has existed on the Earth, virtually all of our technology and most of what we consider as intelligence has developed over only the last few thousand years. Hence extraterrestrial life that has developed more slowly than us by even one part in a million would be no more advanced than cave men, whereas life that developed one part in million more rapidly would be as technologically advanced as we are likely to be in a few thousand years. We would expect some of these civilizations to be many millions of years more advanced than us. Since we have no reason to believe that we are anything but typical, I must conclude that there are countless civilizations more advanced than us.

If that is so, then why is there no evidence for it? As Enrico Fermi quipped in 1950, 'Where is everybody?' (the Fermi Paradox).

A fifty-year radio search for extraterrestrial intelligence (SETI) has so far turned up nothing, which is not surprising. Radio would be an ineffective form of communication because of the large time lag resulting from the enormous distance to even the closest stars. Furthermore, broadcasting one's presence entails an element of risk if the aliens turn out to be unfriendly.

One possibility is that whenever a civilization develops the means to annihilate itself as we now have with our nuclear and biological weapons, not much time lapses before someone uses it. We are now living in a time of global terrorism and suicide bombers. There is little question that living among us are numerous individuals who would bring an end to life on Earth if they had access to the means to accomplish it. I'm not confident that we will escape that fate, but it seems likely that at least some of the advanced civilizations in the Universe have been able to avoid self-destruction.

Another possibility is that when a civilization becomes sufficiently advanced, it develops the means for observing us in a stealthy fashion, perhaps from hyperspace or some such. Maybe we are a science fair project for an advanced extraterrestrial child or an exhibit in the zoo of a highly advanced society. But I think it is more likely that we would just not be interesting to a truly advanced civilization. They would regard us as we regard a colony of ants in the forest. They have seen countless such things before and just don't find us sufficiently different or interesting to warrant their attention. Or perhaps they are protecting us from abuse and contamination by others much as we try to protect the natural habitat of plants and animals on the Earth. Of course, some people believe in flying saucers and alien abductions, but I'm strongly inclined to attribute such observations to optical illusions and hallucinations or simple fabrications.

A third possibility, which seems more likely and is not so often discussed, is that the theoretical limits to technology are much more constrained than is commonly assumed. There has been an exponential growth in technology since the dawn of man, and the rate of growth is now comparable to a human lifespan. We live at a time unique in human existence, when the world is a very different place toward the end of our life than it was toward the beginning. There is a tendency to assume this rapid advance will continue and perhaps even accelerate into the indefinite future.

However, one thing we know about exponential growth is that it cannot continue forever. Most things that grow exponentially for a long time eventually slow their growth as the essential resource is gradually depleted, and they follow some sort of sigmoid curve. The resource that enables technological growth is scientific knowledge, and we may eventually exhaust that knowledge as we gain a complete understanding of nature. In such a case, technology would also follow a sigmoid curve, and its growth would eventually diminish. An interesting question is then to ask where we are on that curve. Perhaps we have already reached the inflection point, the point at which the rate of growth begins to decrease, and thus the point at which roughly half of everything that will be invented has already been invented. What is the evidence for this?

Consider just two areas of technology—transportation and communications. Automobiles and airplanes were invented about a hundred years ago, and during the first half of the twentieth century they radically changed the ease of travel, but our cars and planes are no faster and not significantly more comfortable than they were fifty years ago. We are able to travel to anywhere on Earth within a day. Even space travel, which advanced so rapidly during the 1960's, has changed little since then. The telephone, radio, and television were developed in the first half of the twentieth century and have seen only modest improvement since then, cell phones and high-definition digital TV notwithstanding. We can talk instantly to anyone on Earth who has a cell phone or even by video if they have Internet access. Our nuclear weapons have changed little for half a century, and nuclear power—so promising at mid-century—seems to have taken a step backwards. Most of our electricity is still generated by burning coal, a technology that dates back a hundred years, and our cars and planes use the same fuels as when they were invented, although we are on the verge of more widespread use of renewable energy sources and alternate fuels in our cars including electricity.

To be sure, some new technologies have emerged in the last fifty years such as personal computers, the Internet, the global positioning system, new drugs, and advanced medical treatments, but it is is not obvious that those developments exceed those during the fifty years previous to that. New materials, instruments, and techniques have allowed us to make devices that are cheaper, smaller, faster, more efficient, more powerful, more versatile, and more environmentally friendly, but with few exceptions, they have not fundamentally changed what we can do or accomplish as much as did the earlier developments. Thus is seems plausible that the rate of technological advance has already begun to slow.

The understanding of electromagnetism in the mid 1800s led over the subsequent hundred years to most of the mundane technologies that we now take for granted. The understanding of the atom in the early 1900s has over the past hundred years given us our advanced technologies characterized by semiconductor electronics and lasers. The understanding of nuclear reactions in the mid 1900s led to nuclear weapons, nuclear power, and some applications in medicine and elsewhere. With the achievement of controlled nuclear fusion, which may become a reality by mid-century, the applications of nuclear physics may well be largely exhausted. We are now seeking to understand quarks and their interactions, the forces within the nucleus and the great cosmological questions of how the Universe was born and what will be its future. Perhaps some technological applications for that knowledge will emerge over the next hundred years, but the trend seems to be for the technologies spawned by the knowledge we gain to diminish rather than increase.

Charles H. Duell, U.S. Commissioner of Patents is widely reported to have said in 1899 that 'everything that can be invented has been invented,' although there is no evidence that he actually said or even thought that, but that didn't prevent him from being widely quoted and ridiculed. My claim is more modest and in some ways the exact opposite. I think we may now be at a time of near maximum technological advance, but the rate of advance will gradually diminish until we eventually have roughly twice as much technology as we have now, and then we will have developed almost everything permitted by the immutable laws of nature. This may preclude our ever being able to travel to the stars, wormholes not withstanding, or even to communicate with the many distant advanced civilizations that have also achieved this limiting state of development. Our recent rapid progress, aided by the vivid imagination of science fiction writers, has led us to suppose that almost anything is possible. But it may not be so, and the laws of physics cannot be bent, much less broken.

However, doubling the amount of technology we currently have will still produce many marvelous and interesting developments, especially in the biological sciences. I've often thought how great it is to be part of the first generation of humans for which the world will be a radically different place toward the end of our life than toward the beginning. The time-scale for change has suddenly become short compared to a human lifespan, which makes it an interesting (and in some ways fearful) time to live. We can look forward to at least a few hundred more years of rapid development during which time the world will continue to change significantly over a human lifespan, and perhaps one of those changes will be to increase human longevity at a rate sufficient to guarantee that our descendants will find their long lives as interesting and varied as we do now with our sub-century lifespans. Perhaps we will even achieve immortality as we learn to replace all our bodily organs as they fail much as old airplanes can be kept flying forever. Unlike others, I would welcome such a development, although it seems unlikely to happen in my lifetime, but then that's what I said about travel to the Moon when I was too young to know any better.

# Chapter 26

# Immortality

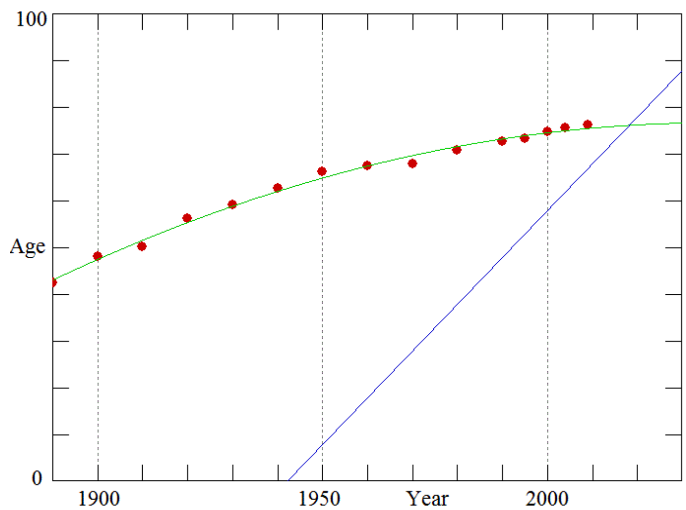
> I don't want to achieve immortality through my work; I want to achieve immortality through not dying. –Woody Allen

I was very young when I realized that people eventually die. While I found that fact rather discouraging, I didn't dwell on it because it seemed so far in the future, and I thought that science might solve the problem of aging before my time was up. Shortly after 1950, I encountered data showing that human lifespan had increased approximately eighteen years in the previous half century. Thus science was extending human life about a third of a year for every year that passed. I hoped that this rate would increase, eventually reaching a rate of one year per year, at which time many of those still living would truly be immortal. I looked for evidence of an increase in the rate at which longevity was increasing, or what in calculus is called a positive second derivative, but I concluded that any such increase was likely too small to save me, although it might benefit the next generation.

I didn't look carefully at the data for another half century, but it was evident that medical science was not advancing as fast as I had hoped. In 2011 at age 69, with better mathematical skills, access to detailed census data on the Web, and computational prowess, I looked again at the data. Predicting human longevity is an important issue for insurance companies and the Social Security Administration, but I went back to raw data deduced from the actual distribution of death ages over the years. However, the average age of those dying in a given year is not the same as the average life expectancy in that year for a number of subtle reasons. For example, consider a population in which everyone is forty years old in a given year.

The average age of those dying then would be exactly forty, but if very few died that year, the average life expectancy could be much longer.

With a minor correction for such effects, the average life expectancy for white American males at birth is shown to have increased from 48.2 in 1900 to 66.3 in 1950 to 74.8 in 2000. Much of this increase was due to decreased infant mortality, but it nevertheless provides an indicator of the advance in medical progress over the Twentieth Century. Unfortunately, a quadratic fit to the data gives a negative second derivative in keeping with my contention that the rate of scientific progress might actually be slowing. While longevity increased eighteen years during the first half of the century, it only increased another 8.5 years in the second half.




Increase in average lifespan of white American males over the Twentieth Century. Red dots are from census data, green is a quadratic fit to the data, and blue is the increase in my age since birth in 1942.

It is risky to extrapolate such a quadratic fit outside the range where data exist, but if one does so anyway, two conclusions emerge: First, average lifespan will top out at 76.7 years in the year 2037 and will thereafter decrease. Second, on average, I can expect to die in 2019 at age 76. This is not a prediction but rather an estimate of the date after which my continued living is at the expense of someone else who died earlier than average. In particular, it ignores the myriad factors that influence lifespan such as genetics, health, lifestyle, nutrition, education, occupation, behavior, and attitude, most of which point to my significantly beating the average. My father died at age 82 and my mother at 90. Even my older brother, who fought obesity most of his adult life lived to be 78. There are many life expectancy calculators on the Web that consider such factors. For example, the one at http://www.livingto100.com/ asks forty questions and predicts that I will live to age 88, which I find more palatable. My bigger fear is that my mind or body could deteriorate years earlier.

Given that I cannot expect physical immortality, is there a sense in which I can live forever? I do not ascribe to the Christian view of life after death in Heaven (or perhaps Hell). However, I take some small comfort in the doctrine of the perseverance of the saints, which is a Calvinist teaching that one who is truly saved cannot lose that salvation, or 'once saved, always saved.' Whether I was truly saved during my religious period in the 1960s is questionable, but I did all the right things back then, and I doubt that I will revive those beliefs as my death approaches. I am comfortable with the thought that my consciousness will end with my physical death, although I strongly prefer to delay that end as long as possible provided my mind and body are intact because I have more things I want to accomplish.

The other way to achieve immortality is through one's work. Certainly Shakespeare, Newton, and Mozart live on through their creative contributions to society. In fact, their lasting influence dwarfs what recognition they enjoyed during life. Of course, these are people with exceptional talent and productivity, but everyone's life affects the future of mankind to some degree. For many people, their progeny are their greatest contribution to society. Without biological descendants, I take special pride in my students, some of whom will surely have a more profound and enduring impact than I have had.

However, it puts one's life in prospective to ask how the World will differ and how one will be remembered, if at all, a hundred years after death. I know that books and scientific publications from a hundred years ago are still readily available in libraries and increasingly on the Web, and that has motivated my drive to author papers and books including these memoirs and to develop a popular website. I also hope that *The Wonders of Physics* program that I started in 1984 will continue in a form traceable to its origin for many more decades, and I have made accommodation for that in my will and in a Memorandum of Agreement with the University of Wisconsin Foundation, copies of which are in my file cabinet at home and held by my attorney, Barbara S. Hughes.

Perhaps the most realistic way for an ordinary scientist like me to achieve immortality is to do something of sufficient importance that one's name gets attached to it. All physicists know Newton's laws, Maxwell's equations, and the Heisenberg uncertainty principle. People in my subdiscipline of nonlinear dynamics, know Lyapunov exponents, the Lorenz attractor, and the Kaplan-Yorke dimension. This desire has influenced my choice of research topics, hoping to discover an equation of sufficient interest that it becomes widely known as the 'Sprott equation.' I have proposed countless equations of minor interest but not one of over-riding importance or significance. However, occasional papers now refer to 'Sprott equations,' 'Sprott systems,' or 'Sprott circuits,' which gives me a degree of satisfaction similar to winning the Nobel Prize for scientists of greater statue. I can only hope that such nomenclature will become a standard part of the lexicon of science.

Given the certainty of my eventual death, I will here detail my wishes for those who are left to decide how to respond to it, especially if I should die suddenly and unexpectedly, which is preferable to a long period of pain and declining abilities. The general principle is that I want to live as long as possible, but not in a vegetative state, kept alive by machines with little hope of recovery, and I do not want to consume the value of my estate through prolonged end-of-life care. I am not philosophically opposed to suicide, assisted or not, to hasten my inevitable end, although it is hard now to imagine summoning the courage to carry that out or to place the burden of assisting me on someone else.

When I drafted my will in 2003, I designated Deborah J. Aks as my health care power of attorney to carry out my wishes for end-of-life medical decisions. She is significantly younger than I, has good common sense, and at the time lived right next to the University of Wisconsin Hospital, although she subsequently moved to New Brunswick, NJ where she is currently a research professor in the Rutgers University Center for Cognitive Science. Normally, one might designate such power to a spouse, but I was unmarried at the time and not in a serious relationship, and I feel that such power is best vested in a trusted individual who would make such decisions objectively and without undue emotion.

If I am married when the time comes for such action, I hope that Debbie will take into consideration the wishes of my wife and discuss with her any decisions that are made. In particular, we decided that they should pull the plug on life support if the chance of my recovery is less than $1/\pi^3 \cong 3.225\%$. Of course, this number is ridiculous, but it is specific, and it transfers the burden of decision to the doctors who would have to assess my probability of recovery. That might be a good time to get a second and third opinion before taking action, and I note that there is a 'minimally conscious state' from which people occasionally recover and in which one's consciousness can be ascertained by checking for eye tracking of one's face in a mirror. Debbie is a good person to perform such a test since vision is her research specialty, and we coauthored a paper on eye-tracking. If I am slowly dying with minimal need for medical treatment, I would prefer to remain at home with whatever professional nursing care is necessary for my comfort and needs without overly burdening my loved ones.

I have never been one to make much ado about holidays, birthdays, weddings, and the like, and so I would not expect or wish anything special at my funeral. Clearly, any memorial would be entirely for the benefit of those that I leave behind and will be of no benefit or comfort to me. Feel free to donate any of my organs that would be of use to others, but I would rather not use my body as a cadaver for the education of medical students. I have already done enough for the next generation of doctors by teaching them physics, and I have seen their sometimes clumsy work in the physics lab. I would prefer to be cremated rather than consuming valuable real estate in a cemetery, but I will leave it for others to decide what to do with my ashes. If anyone cares to make a monetary donation in my memory, make it to 'The UW Wonders of Physics Fund.'

Three things are of paramount importance to me in preserving my legacy: 1) continuation of *The Wonders of Physics* program including the annual presentations to the public and the traveling show, 2) the preservation of my website 'Sprott's Gateway' in some form, and 3) the publication and dissemination of my papers and books including this document. Those who want to honor me in some way can do so by tending to these matters after they are out of my control.

Donate the books in my personal library on campus and at home to the UW Library System, especially to the Physics Library. Give anything of special sentimental value or personal importance to my wife and friends. Sell anything else of value to maximize the value of my estate and apply it to the purpose detailed in my will.

Grieve briefly for me, and then enjoy your own lives. Follow your passions, work hard, and try to maximize your positive influence in the World. Life is short and precious, and you should make the most of yours and try to accomplish some of the things I would like to have done if I had been smarter and lived longer. All-in-all, it's been a pretty good ride.

# Appendix A

# Family Tree

One day in 1999 a mysterious mailing tube arrived at the door. Inside was a large sheet of paper upon which someone had carefully printed the names of my relatives going back six generations, only a few of whom I recognized, showing their relationship and dates of birth and death. There was no explanation, but the mailing label indicated that it came from the family office supply store in Memphis of which my now deceased brother was then the owner. This was shortly after my brother remarried, and I speculated that somehow his new wife Mara Fulghum, whom I have never met, was somehow involved.

I had never been particularly interested in my genealogy or even been much in touch with my relatives since leaving Memphis for college forty years earlier. I somehow thought that my ancestry was Scandinavian, and I knew very little about my grandparents, all of whom died before I was born. I knew that my great grandfather died fighting in the Civil War for the Confederacy. I decided it would be fun to digitize the data I had acquired and to put it on my website.[1] Various relatives found the website and provided corrections and additional fascinating information.

I learned that my branch of the Sprott family originated in Scotland and migrated to Northern Ireland for a few generations. In 1838, Robert Sprott (1808–1862) decided to try his fortune in the New World, and came to Philadelphia from County Down, Ireland. He remained there for eighteen months before joining his brother Samuel Sprott who had arrived in Charleston, South Carolina in 1828 and then moved to Alabama. Robert

[1] See History of the Sprott Family at http://sprott.physics.wisc.edu/famhist.htm.

Sprott was a rather unsuccessful farmer, but he had seven children, including three boys who were in the Confederate Army. One of these, James Sprott (1834–1864) served in Alabama's Forty-second Regiment and was mortally wounded at the Battle of New Hope Church, dying a week later in Atlanta. Before he died, he fathered three children, one who died as an infant, a daughter, and a son, William Leonidas Sprott (1862–1940) of Memphis, Tennessee, who was my grandfather. My grandfather had two sons and six daughters, all of whom married and lived in Memphis—except for one who moved to New Orleans—and became part of the large family of aunts, uncles, and cousins that I knew as a child.

Only years later did I realize how odd it was that my father and his siblings remained a close-knit family all their lives, while their spouses, even the men, did not seem close to their blood relatives. In fact, I cannot recall a single such relative except for my mother's two sisters. The men seem to have been totally absorbed into the rather large Sprott family, from which I conclude that our large extended family was probably more the exception than the rule in that era.

Particularly interesting is that James Sprott who died in the Civil War had a brother Samuel Henry Sprott (1840–1916) who fought in Alabama's Fortieth Regiment and eventually rose to the level of Captain. After the war, Samuel became a lawyer and served as circuit judge in Alabama for twenty-eight years until his retirement in 1910. Commencing in 1899, he wrote his own memoirs, lucidly recounting his experiences and the life of a common soldier in the Civil War. A hundred years later, his memoirs were discovered in the estate of one of his descendants and published as an edited book.[2]

A portion of my family tree, omitting the ancestors of my mother and other spouses as well as some individuals who were subsequently determined to be adopted and their offspring, is shown in the table that follows, along with dates of birth and death where those are known. I know relatively little about my mother's ancestors, although the original data included names and birth dates of her parents and the names of three of her grandparents. It is my hope that other relatives and future genealogists will fill in additional details so that my genetic connection can be traced to the largest possible number of relatives.

[2]Samuel H. Sprott, *Cush: A Civil War Memoir*, Livingston Press: Livingston, AL, 1999, edited by Louis R. Smith, Jr. & Andrew Quist.

Family Tree

1 John Sprot
. +Elinor Atkin
. 2 James Sprot 1754–1846
.... +Margaret Hamilton 1764–1846
.... 3 Robert Sprott 1808–1862
....... +Mary Bothwell 1807–1882
....... 4 Mary Jane Sprott 1832–1832
....... 4 James Sprott 1834–1864
.......... +Esther Boone
.......... 5 Mary Elizabeth Sprott 1860–1955
............. +Thomas N. Rogers
............. 6 Thomas Sprott Rogers 1892–1981
................ +Ruth Olive Wilson
................ 7 Infant Rogers 1925–1925
................ 7 Elizabeth Lee Rogers 1929–
................... +H. C. Fryar
................... 8 Thomas Curtis Fryar 1954–
...................... +Brenda Sue Smart 1950–
...................... 9 Leah Christine Fryar 1982–
...................... 9 Megan Ruth Fryar 1986–
................... 8 William Frank Fryar 1959–
...................... +Margot Maurine Chartrand
...................... 9 Kristryn Marie Fryar 1986–
...................... 9 Henry Curtis Edward Fryar 1988–
...................... 9 Eric Franklin Chartrand Fryar 1990–
................... 8 Eric Carter Lee Fryar 1964–
...................... +Stephanie Lynn Beeman 1970–
...................... 9 Mackinzie Blake Fryar 1989–
................ 7 Ruth Olive Rogers 1930–
................... +James Harry Soffos
................... 8 Beverly Sue Soffos 1951–
...................... +Mackie Pierce
...................... 9 Wendy Leigh Pierce 1976–
...................... 9 Lindsay Ellen Pierce 1980–
................... 8 James Harry Soffos 1954–
...................... +Katherine Sanders

...................... 9 Stacey Renee Soffos 1977–
...................... 9 Rebecca Elaine Soffos 1982–
................... 8 Thomas Michael Soffos 1955–1998
...................... +Carla J. Butler
...................... 9 Ambra Collen Soffos 1978–
...................... 9 Michael Soffos 1984–
............. 6 Virginia Page Rogers 1889–
................ +Thomas Clayborn Epperson
.......... 5 William Leonidas Sprott 1862–1940
............. +Sarah Bettner Wilson 1869–1941
............. 6 Reba Lucille Sprott 1891–1966
................ +John Herring
................ 7 Dorothy Eleanor Herring 1925–
................... +Edward L. Lang
................... 8 Reba Louise Lang 1948–
................... 8 Dorothy Adele Lang 1952–
............. 6 Marie Louise Sprott 1893–1983
................ +Eustice Jackson 1886–1940
................ 7 Eunice Jackson
............. 6 Sadie Chandler Sprott 1896–1986
................ +Julien L. Cox 1891–1961
............. 6 Willie Maie Sprott 1898–
................ +Sterling L. Stanley
................ 7 Richard Stanley
................... +Virginia Weller
................ 7 Robert Stanley
................... +Al Gine Kirkland
............. 6 William Leonidas Sprott, Jr. 1908–1984
................ +Evelyn Peters
................ 7 William Sprott
................ 7 John Sprott
............. 6 Frank Wilson Sprott 1910–1992
................ +Ila Fern Tidwell 1912–2002
................ 7 Frank Wilson Sprott, Jr. 1931–2009
................... +Roalise Elizabeth Chambers
................... 8 Frank Wilson Sprott III 1957–
...................... +Harriett Sayers 1958–
................... 8 Sherri Sprott 1959–

...................... +Maurice A. Ethier
...................... 9 Ashley Elizabeth Ethier 1983–
...................... 9 Sean Evan Ethier 1985–
...................... 9 Matthew Ryan Ethier 1987–
................ *2nd Wife of Frank Wilson Sprott, Jr.:
................... +Mara Regent Fulghum 1948–
................ 7 **Julien Clinton Sprott 1942–**
................... +Mary Ann Royal 1942–
................ *2nd Wife of Julien Clinton Sprott:
................... +Dan Zhu 1964–
............. 6 Yetive Calhoun Sprott 1911–1982
................ +Leslie G. Bone 1905–1975
................ 7 Leslie Bone 1941–1944
............. 6 Udell Sprott 1912–
................ +John S. Letellier
................ 7 Yetive Letellier
................ 7 John S. Letellier
.......... 5 Infant Sprott 1864
....... 4 John Sprott 1837–1874
.......... +Mary Evans 1852–1873
....... 4 Samuel Henry Sprott 1840–1916
.......... +Leonora A. Brockway 1849–

# Appendix B

# Books Published

Writing books was never one of my life objectives, although I always enjoyed writing. I don't consider myself an especially skilled writer despite having spent a great deal of time editing the English of my students and collaborators. I am grateful for the solid grounding in grammar that I got as a young student even though I did not enjoy English classes nearly as much as science and math classes.

Each book in the list that follows arose out of a perceived need or an idea that seemed to require more than the usual journal publication. Completing a book and seeing it on the bookshelf has provided a great deal of satisfaction, and the royalties that dribble in for years afterward are not a bad reward either, although the monetary return per hour expended would not have justified any of these projects. These works constitute an important and hopefully enduring component of my legacy.

Books Published

- *Introduction to Modern Electronics* (John Wiley & Sons: New York, 1981) TK7815 S72, ISBN 0-471-05840-8 (out of print)
- *Numerical Recipes: Routines and Examples in BASIC* (Cambridge University Press: New York, 1991) QA297 S68 1991, ISBN 0-521-40688-9
- *Strange Attractors: Creating Patterns in Chaos* (M&T Books: New York, 1993) QA614.86 S67 1993, ISBN 1-55851-298-5 (out of print, but the manuscript is available in HTML, PDF, and Microsoft Word format)
- *Chaos and Time-Series Analysis* (Oxford University Press: Oxford, 2003) Q172.5 C45 S67 2003, ISBN 0-19-850839-5 (hard cover) 0-19-850840-9 (paperback)
- *Images of a Complex World: The Art and Poetry of Chaos* [with Robin Chapman] (World Scientific: Singapore, 2005) QA845 C46 2005, ISBN 981-256-400-4 (hard cover) 981-256-401-2 (paperback)
- *Physics Demonstrations: A Sourcebook for Teachers of Physics* (University of Wisconsin Press: Madison, 2006) QC30 S67 2006, ISBN 0-299-21580-6
- *Elegant Chaos: Algebraically Simple Chaotic Flows* (World Scientific: Singapore, 2010) QA614.82 S67 2010, ISBN 978-981-283-881-0
- *2-D Maps and 3-D ODE's: A Rigorous Introduction* [with Elhadj Zeraoulia] (World Scientific: Singapore, 2010) QA243 Z47 2010, ISBN 978-981-4307-74-1
- *Frontiers in the Study of Chaotic Dynamical Systems and Open Problems* [edited with Elhadj Zeraoulia] (World Scientific: Singapore, 2011) ISBN 978-981-4340-69-4
- *Robust Chaos and its Applications* [with Elhadj Zeraoulia] (World Scientific: Singapore, 2011) ISBN 978-981-4374-07-1

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