Chapter 7
Graduate School -
The University of Illinois

The last two years in college involved serious consideration to three matters in addition to my studies. First, was graduate school - which one? Second was financial support - could I get a scholarship or fellowship to support my graduate studies? Finally, there was the draft - could I get a 1-W classification as a conscientious objector?

The decision on graduate school was fairly simple. I applied to, and was admitted to, several: Columbia University, the University of Illinois, the University of Michigan, and the University of Wisconsin. Partly because in was my home state, partly because it was Bradley Burson's alma mater, and partly because, if I didn't get financial support, I had in-state tuition, I chose the University of Illinois.

To finance my graduate education I applied for both a Danforth and Woodrow Wilson Fellowship. I was interviewed by a faculty committee at Notre Dame University for the Danforth Fellowship and at Northwestern University for the Woodrow Wilson Fellowship. The Danforth Fellowship had some specifically religious overtones, and I suspect that the committee sensed my religious confusion and decided not to award me a fellowship. However, the Woodrow Wilson committee concluded that I was indeed interested in an academic career and did award me a fellowship. The stated objective of the Woodrow Wilson Fellowship is to encourage young people to become college professors.

Alma Mater and Altgeld Hall

The Viet Nam war was raging during my college and graduate school days. I was totally against this war, and, heeding the church's teaching about pacifism, I applied for a 1-W classification (non-combatant service). The local draft board indicated to my Mom that they did not give such classifications. So I appealed their 1-A decision to the state of Illinois draft board, and had a hearing in Chicago before a judge. I did have a good pastor along to represent me. However, the judge said that since I had worked one summer at Micro Switch, and Micro Switch made switches which were used in Air Force war planes, this experience was inconsistent with my pacifist position. So he denied my request for a 1-W classification.

Finally, I appealed this decision to the Presidential Appeal Board made up of one protestant, one Catholic and one Jew. They reviewed my case, and by a 2-1 decision classified me 1-W. By this time the war and draft were over.

My first year in graduate school was mainly academic. Both semesters I took four units to get the eight units required for a Master's degree in physics. My strongest memory of that first year was wrestling with Quantum Mechanics. Three semester of QM were required, and we studied from David Bohm's book, *Quantum Mechanics.* David Bohm was a friend of Albert Einstein, and both he and Einstein worried about the concept of *entanglement* implied by Bohr's interpretation of quantum mechanics. He was also a Communist and lost his U.S.citizenship in the McCarthy hearings.

My second year at the University of Illinois I became a half time teaching assistant, teaching the beginning physics laboratory under the direction of Dr. Leo Lavatelli. He was a master teacher with about twenty five grad students and post docs to assist him in offering first year physics. One of my colleagues in this course was Robert Schrieffer, Nobel laureate. The second major commitment my second year was to study for the qualifying exam. Near the end of this year I took the "quals" as they were called, and was one of the nine students passing out of the twenty seven who took it. What a relief! Many who flunked it dropped out of graduate school with a Masters Degree. One could take it only twice.

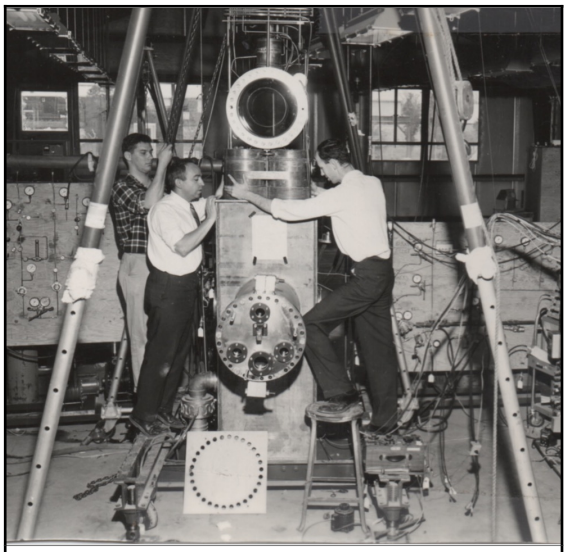

Control Pannel on Betatron

During my first three years of graduate school I had a number of excellent courses which stick in my memory. Among them was a three semester course in electrodynamics from the notes, soon to become a best selling book, by Dr. J. D. Jackson. Problem assignments in this course were horrendous, typically 15-20 pages of mathematics. Nuclear physics from Dr. Hans Frauenfelder was clear and well presented, and I became one of the graders for this course. Reactor physics by Dr. Felix Adler included analog computing to calculate the neutron flux throughout the reactor core. I studied one semester of semiconductor physics from Dr.

John Bardeen who won a Nobel Prize for the discovery of the transistor and another Nobel Prize for the theory of superconductivity. Dr. K. Nishijima taught the course in elementary particles which I took. He had discovered the property of strangeness which was particularly useful since my thesis was on strange particle production.

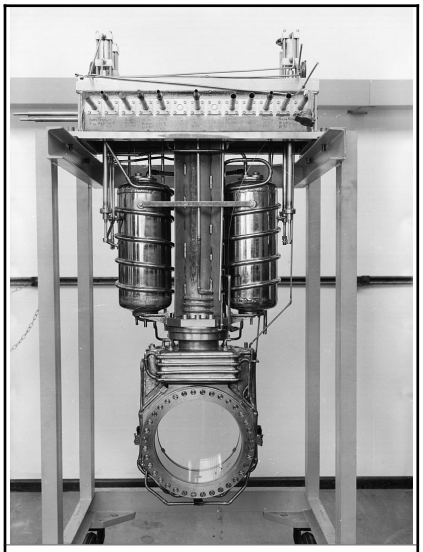
Two of my math courses were memorable. Franz Hohn taught the course in matrix algebra from his own text, Elementary Matrix Algebra. It was an excellent course and I loved it. Franz was on my Ph.D. examining committee. On the other hand, vector and tensor calculus taught by Professor Ray Langebartel I found very difficult. I never did master the Einstein general relativity tensor.

By my third year in graduate school I was ready to start my thesis. Since the physics department had no active research in gamma ray spectroscopy, I migrated into the high energy physics program headed by Dr. Edwin L. Goldwasser. Here Jim Simpson, Dr. Goldwasser, and Dr. Uli Kruse are working on the Midwestern Universities Research Association (MURA) 30 inch bubble chamber.



The MURA 30" Bubble Chamber

My first research assignment was to assist Arthur Walker complete his thesis research on the 300 MeV Illinois betatron. Dr. Donald Kerst had invented the betatron at the University of Illinois, and Arthur was measuring the cross section for the production of pi mesons. The data was recorded by a trace on the oscilloscope, and it was my job to record these images on Polaroid film at regular intervals.



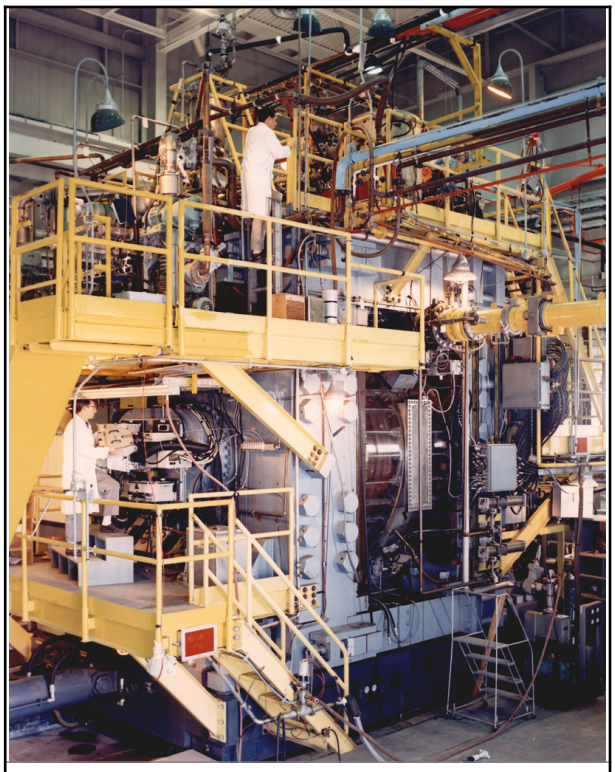
The MURA 30" Bubble Chamber

The instrument of choice, at the time, was the bubble chamber. It had been invented by Donald Glaser who was inspired for the discovery by observing a string of bubbles across his beer glass. He got the Nobel Prize for his discovery.

The machine on which the film for my thesis was taken was the Brookhaven National Lab's 80 inch hydrogen bubble chamber. It was 20 feet high, 28 feet long, 13 feet wide and weighed 450 tons. It contained 1500 liters of liquid hydrogen at -400° F, had a 6.5 inch window, and a 36 inch piston to pulse the pressure. It was the world's largest bubble chamber.

The principle of the bobble chamber is really quite simple. When a superheated fluid is disturbed in some

way, such as a charged particle passing through it, a thin row of bubbles will form along the path. These bubbles may be photographed and will mark the path of the charged particle. Thus bubble chambers all have at least one clear glass window, a light source, three of four cameras allowing stereoscopic photography and exist in a strong magnetic field.

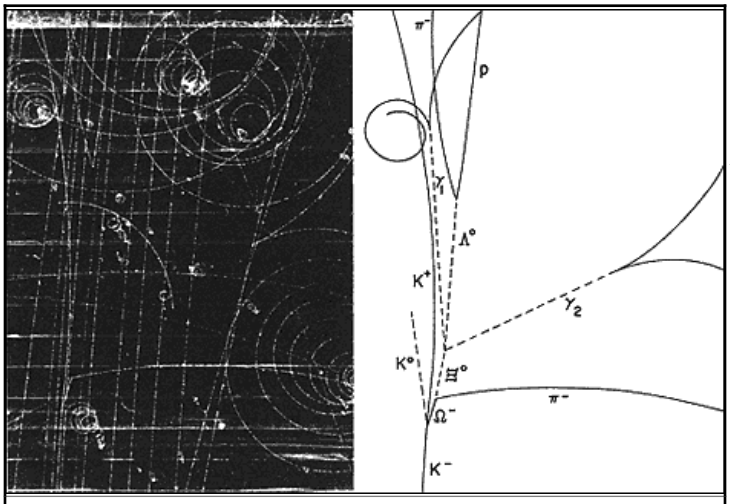


The Brookhaven 80" Bubble Chamber

As I recall, we spent about a week at the Alternating Gradient Synchrotron (AGS) at Brookhaven, taking forty 1000 foot rolls of 70 mm film from three cameras. The AGS pulsed once per second, the 36 inch piston pulsed upward, superheating the hydrogen, and a total of 37,000 photographs were taken from three views simultaneously.

My thesis was entitled *Strange Particle Production in 8 BeV/c Proton-Proton Interactions*. The AGS accelerated 10-15 protons to a momentum of 8 GeV/c each second, and there was a finite chance that they would collide with the proton nucleus of the hydrogen, and in the collision, produce strange particles. Strange particles were identified on film by their decay products - charged strange particles decays produce a "kink", and neutral strange particles decay into two charged particles, observed as a "V".

My experiment was the third run on the 80" bubble chamber by the U.of Ill. group. By this time we had expanded our analysis lab to include about fifteen scanning machines, two measuring machines, and about thirty "scanners", student carefully trained by physicists to scan and recognize important bubble chamber phenomena.



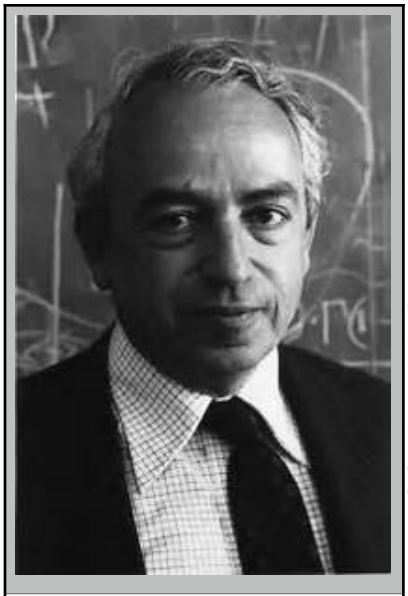
Discovery of the Omega-Minus Particle

To give you an idea of what the analysis of bubble chamber photographs involved, I include here a photo of the discovery of the Omega-minus particle. This is perhaps the most famous photograph ever taken on the 80" bubble chamber.

Our scanning instructions were very specific: any 2, 4, 6, or 8 pronged event with one of more associated kinks or Vs was identified as an event. My 195 page thesis calculated the likelihood (cross section) for some 33 possible strange particle reactions. The strange particles we detected were of two classes: K mesons (K^+, K^0, K^-) and baryons (heavy particles Λ, Σ^+, Σ^0, Σ^-). For the events we were able to measure and identify we measured the cross section to be 946 ± 40 μb, and estimated, when all the efficiencies were taken into account, the total cross section for strange particle production to be 1823 μb. (1 μb = 1 micro-barn = 10^{-30} cm^2) These figures are based on 1012 measured and identified events.

It should be emphasized that the analysis process was an extremely well documented and meticulous process. Once the scanners found an event, they took an $8_{1/2}$ by 11 inch image of it, including the scanners name, the date, the roll #, the frame #, and the event type. These data sheets were passed on to the measurers who mounted the three rolls of film on their measuring machine, and measured 5-15 points on every track, kink , and V to 2/1000 of an inch in real space. Their measurements were recorded on computer cards which were sent to the IBM 7094 computer every evening for analysis.

The analysis program had the embedded magnetic field for determining the particle's momentum and had at least all 33 particle interpretations possible. It applied momentum and energy conservation to the tracks to see which interpretation fit best. If all the particle tracks were visible and measured, it could perform a 4 constraint fit (3 momentum variables and 1 energy variable) to give an iron clad interpretation of the event. If one particle was missing, it could still perform a 1 constraint fit to some interpretation, giving a less iron clad but believable interpretation. It was left to the physicist (me) to scan page after page of computer output, some times 30 - 40 pages per event, to identify which fit was best.



Dr. Edwin L. Goldwasser

This led to a rather humorous classifications scheme for high energy physics grad students: if the stack of computer output in his office was only 2 - 3 feet high, he was a relative "newbie". If the stack of computer output was more than 6 feet high, he had been working on his thesis for many years.

One of the valuable aids in writing the thesis itself was my access to an IBM Selectric typewriter with an English and Greek print ball. Whenever I had to type a Λ, Σ, σ, or μ, all I had to do was exchange the Greek ball with the English ball. Thus, I began writing well before all the data had been analyzed.

On June 2, 1966, Ned Goldwasser, my advisor, and Gerry Almy, the Head of the Department, signed off on my thesis as did my thesis committee consisting of Ned, Gulio

Ascoli, Bob Sard, J.D. Jackson, and Franz Hohn from the Math Department. In retrospect I've come to appreciate what a fine group of academics my committee was. Ned Goldwasser had a tremendous impact on the world of physics. He was author of a fine book on optics, he was leader of a consortium with MIT to develop a new and effective high school curriculum in physics, he was on the site selection committee which picked Fermilab as the site of the National Accelerator Laboratory, and he was the first deputy director of that laboratory.

When Ned retired from Fermilab to rejoin the University of Illinois to become Dean of the Graduate School, Dr. Robert Wilson, the first Director of Fermilab had this to say: "I have been honored and privileged to be associated with this great physicist and lovable man in the adventure of Fermilab." In car rides to Argonne to work on the ZGS he and I would have serious discussions on the role of the church in society, and his position would be very similar to mine of later years. Although much less accessible than Dr. Morris, he played the same role in my graduate school as Dr. Morris had at Manchester. He was a great mentor.

Of course my social and personnel life did not come to a halt during graduate school. Joyce Maier and I had become engaged during one of her visits to Manchester toward the end of my Senior year. Following was a quite romantic summer at Argonne and then regular visits at the University of Illinois and North Central College where Joyce enrolled as a Freshman. She stayed with Haven Palmquist when she visited Illinois, and I stayed at her home in Lombard when I visited.

My first year of graduate school, I roomed with Dick LaBarge, also a physics major, in the graduate dorm, Taft Hall. Dick was an opera singer and had a huge collection of 33⅓ opera records. I had a very good turntable, amplifier, and speaker which I purchased during my Argonne days. So I had to either learn to love opera or die. I learned to love opera, and Joyce and I heard our first live opera at the new U. of Ill. stadium. Dick was one of my ushers at our wedding.

Joyce Maier at home

Our graduate school days were very formative socially. In addition to our marriage and starting our family, we made many friends, some of with whom we continue to visit and communicate. The next chapter gives a detailed description of our wedding, so here I describe some of our friends and activities.

The Thanksgiving before our wedding, Joyce, her parents, and I visited Howard and Ina Long in Overbrook, Kansas. They were Joyce's grandparents on her mother's side. While there, several of us went hunting on

Game Shot on Grandpa's Farm

Howard's farm. Since I had no gun, Howard loaned my his Winchester 12 gauge shotgun.

My luck was good, my aim was straight, and I got several rabbits and a quail or two. This impressed Grandpa Long, and from then on I was accepted into his family!

Perhaps our most rewarding friendship from our graduate school days was with Van and Polly Bluemel. Van had been a Senior when I was a Freshman at Freeport high school and played in the band during our MicroMen's chorus performance. Amazingly, we were both in our first class in quantum mechanics and instantly recognized each other the first day of class. Our first year at Illinois, he married Polly and I married Joyce. Our daughters, Susie and Lee were born on the same day.

Van and Polly Bluemel

Van did this thesis on the Illinois cyclotron at the same time I did mine on the AGS. He went on to teach physics at Wooster, Technical Institute in MA, while I went on to teach physics in the University of Wisconsin system. We visited them in Massachusetts and they visited us in both Wisconsin and Florida. Unfortunately, recently Van died.

Another couple we quickly became familiar with were Joe and Laura Kane. Joe was also in physics and went on to the University of Maryland where he wrote a fine, general physics textbook. Here we are having a picnic with all four friends.

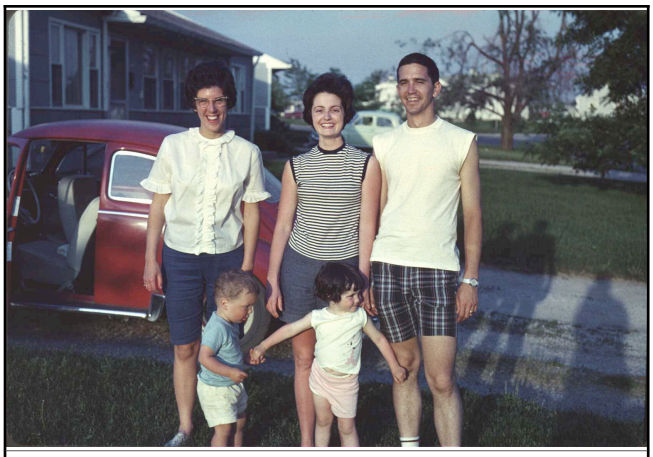
Polly, Van, Laura and Joe Kane

My second year in graduate school Joyce and I lived in the student-staff apartments, right across from the

Physics Department on Green Street.

It was one big living/bed room with a tiny kitchen and bathroom, but at $70/month it was easy on the budget. We lived on the fifth floor of the six floor apartment building. Riding the elevator together we got to know Danny and Greta Wilkenson from Kentucky. We became life-long friends with them. Danny was in plant pathology, and became the chief pathologist for the Pioneer seed corn company in DesMoines, IA.

Joe and Alice Kane and Joyce



Danny, Greta, their Melissa, our Steve, and Joyce

After our son, Steve, was born we moved to a quadruplex in Fairlawn Village. We had a huge front lawn with quadruplexes on three sides and a nice garden in the back. We quickly made friends with our roof mates, Barb and Bernie Wall. Bernie was studying veterinary medicine. He practiced his whole career in Maine, but we still exchange Christmas letters.

To save money Bernie and I soon learned that we could serve each other as barbers. As they prepared to move to Maine, Bernie offered to teach Joyce how to cut my hair. She quickly learned, and has been my barber ever since.

Bernie and Barb Wall

Two more couples played active rolls in our social life during our graduate school days.They include John and Pat Bramson and Jim Loos and his wife. John did his undergraduate studies at North Central College where Joyce did her Freshman year. When John came to the University of Illinois for graduate work in mathematics, we all became friends.

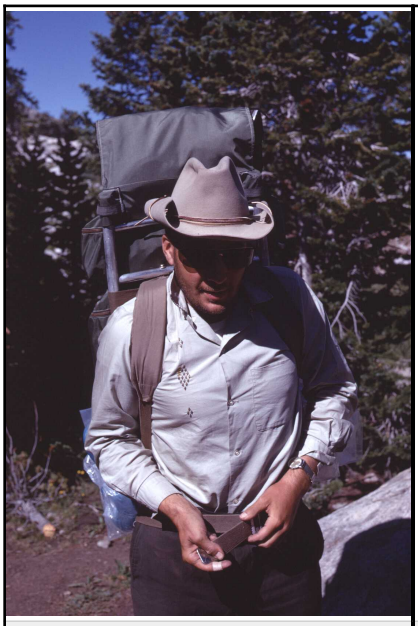
Pat and John Bramson

We visited Pat and John at their home in Boulder, CO, where John became professor and the University of Colorado. Throughout his career John continued to be a major benefactor of North Central. Pat was very active in art. After their divorce we lost track of them.

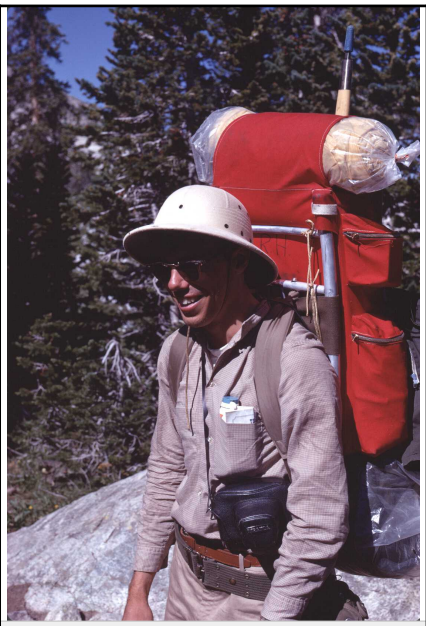
Jim Loos was my colleague in the Physics Department at Illinois. His family, the Wilkensons, and our family frequently exchanged baby sitting roles since our children were all about the same age.

Jim Loos and Family

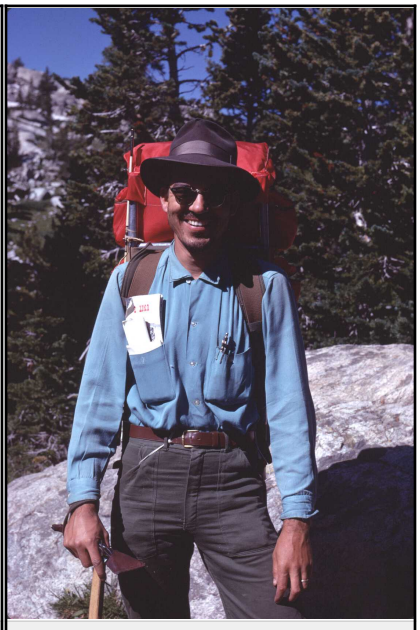
Around 1966 one of our fellow grad students did a slide show on the Wind River range of Wyoming. Several of us decided that we would go too, and the next year Jim Loos, Ray Hanft, Guy Scharf, Joyce and I headed west. Jim, Ray and I actually went backpacking for a week in the Wind Rivers, and Joyce and Guy stayed back and did touristy things. We had a great time, climbing at



Jim Loos



Ray Hanft



Me

least three of the major peaks; Jackson Peak, Cairn Peak and Fremont Peak, the third highest mountain in Wyoming. It was my first of many visits to this magnificent range on the continental divide.

I'll close this chapter on our graduate years with the discussion of two events which greatly influenced our lives. The first was the discovery of Unitarian-Universalism. The second was the birth of Steve, our first child.

My first year of graduate school I had no need nor time for church. After our marriage in the York Center, IL, Church of the Brethren in 1960, Joyce and I rather naturally attended the Champaign Church of the Brethren. After several weeks we had not heard a single new idea and were totally uninspired. So we switched to the campus Methodist church which was one block west of our student-staff apartment. They had two ministers, one young and one older, and both opposed to the war in Viet Nam which was raging at the time. Since we both felt that way, we were quite happy with that church. In fact, we were there and watched as they added the church steeple, making it one of the most beautiful churches in either city.

Wesley Methodist of Urbana - no Steeple

Wesley Methodist Church Now

Unfortunately, the Methodists are not congregational. A couple of years after we started going, the church authorities replaced our two favorite pastors with an ex-Catholic. We found him to have nothing in common with our beliefs. So we switched to the campus Presbyterian church whose minister we rather enjoyed. However, one Sunday morning we were walking on campus and ran across the Channing-Murray Foundation, the student Unitarian-Universalist church (at the time, it was the only campus UU church in America). We wandered in and heard a most wonderful sermon by Rev. David Cole. The UU church's list of principles was al-

most precisely the same as ours. We soon discovered the Urbana UU church and have been UUs ever since.

Channing-Murray Foundation Student UU Church

Probably the biggest blessing of our graduate school days was the birth of our son, Steven. Expecting a new child caused us to move from the one-room student-staff apartment to the much more spacious two-bedroom Fairlawn Village.

Most of the families in Fair Lawn Village were similar to ours, with children around Steve's age for playmates. It was an ideal environment for raising a family. One of the most impressive personality characteristic's of Steve was that he was a "happy baby". Rarely did he cry or show lack of interest in what we were doing.

Of course, Steve was a big hit with our relatives. Here is Steve on the farm with my folks picking flowers.

Steve and Mom

Steve and My Parents

Having climbed nearly all of the Tetons, many of the Wind Rivers, a fair share of Colorado's 14,000 footers, and several in the Canadian Bugaboos, I hoped the climbing gene was heritable. So I was especially pleased with the following photo which seems to confirm that it is. Since this photo, Steve had climbed many of the Tetons

Up Rope!

and Wind Rivers, both with me and, more recently, with his own boys. It does seem heritable (but also environmental).

Amy Wall was Barb and Bernie's oldest daughter and lived next to us on our east side. She was about one year older than Steve and rapidly became his buddy and playmate. Here they are helping me plant the garden!

Speaking of which, we had beautiful gardens in Fairlawn Village. We raised vegetables of all types, but my best achievement were some twelve foot tall Russian sun flowers. We left their foot wide seed pod to serve as bird food for winter birds. It was deep, rich. black soil and a relaxing relief from our academic work.

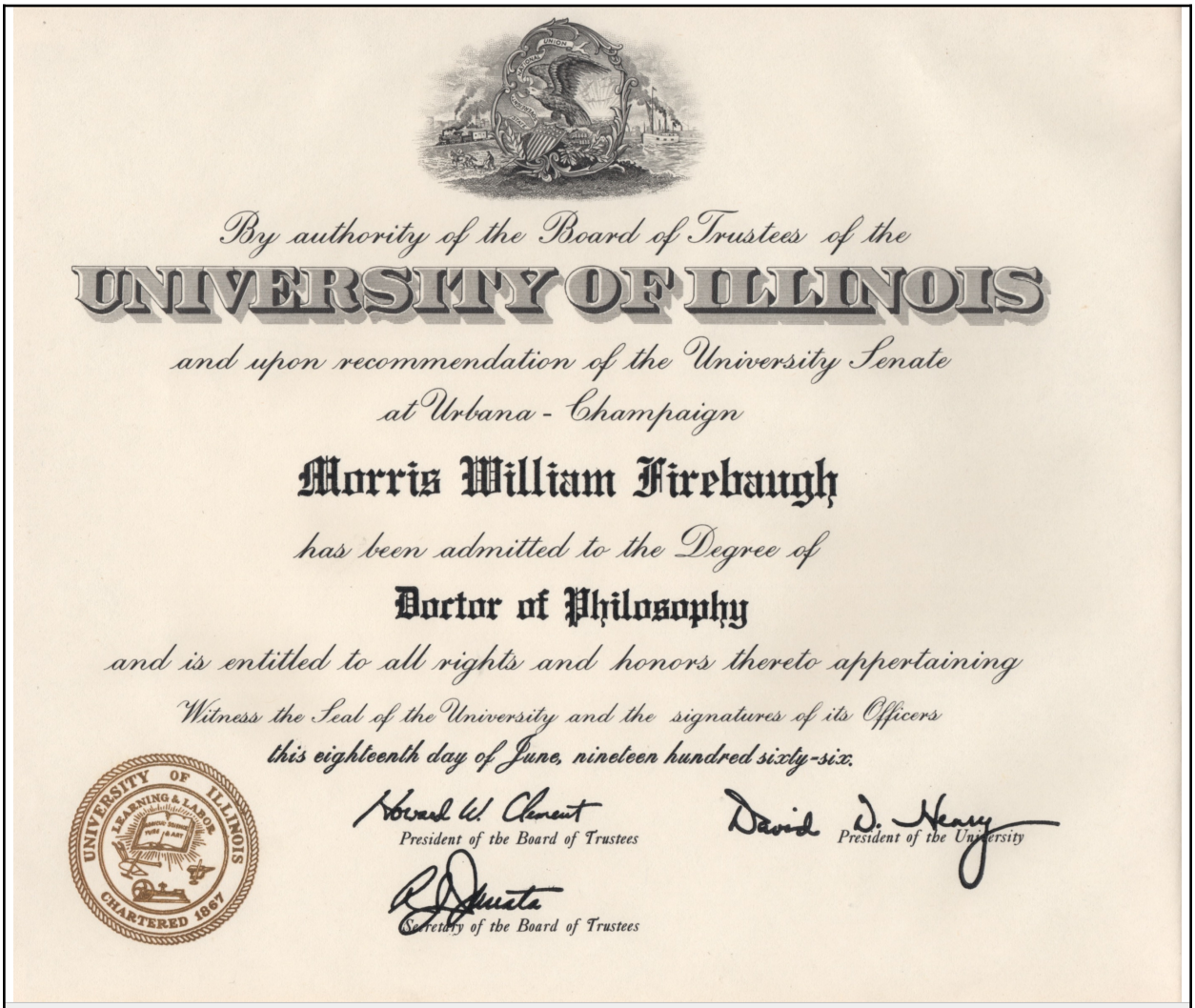
Our years of graduate study were some of the happiest of our lives. The epiphany of the UU religion provided meaning to our lives. Our expanding family offered direction we were to follow in selecting careers. Here are the gowns we wore at graduation and the diploma that proves the degree is real. Joyce received her Master's degreee in Education the same day as I received the Ph.D. The knowledge we gained during our graduate school days enabled us each to carry out our professions.

They were good years!

Joyce in the Garden

Steve and Amy

My Ph.D. and Joyce's Masters Gowns



By authority of the Board of Trustees of the

UNIVERSITY OF ILLINOIS

and upon recommendation of the University Senate

at Urbana - Champaign

Morris William Firebaugh

has been admitted to the Degree of

Doctor of Philosophy

and is entitled to all rights and honors thereto appertaining

Witness the Seal of the University and the signatures of its Officers

this eighteenth day of June, nineteen hundred sixty-six.

UNIVERSITY OF ILLINOIS LEARNING & LABOR CHARTERED 1867

Howard W. Clement
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My Ph.D. Diploma