Albert W. Overhauser Interview

Conducted by Katherine Markee on March 18, 2010

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The following interview was conducted with Albert W. Overhauser (AO) for the Purdue University Oral History Project. It took place on Thursday March 18, 2010, Stewart Center. The interviewer is Katherine Markee (KM), the Oral History Librarian. Also sitting in is his wife Margret.

KM: Thank you and good morning and welcome.

AO: Good morning, thank you.

KM: Let's start off by telling me where and when you were born and your parents and early years.

AO: I'll try. I was born in San Diego, California in 1925. The reason we were there is in 1915 during WWI my father enlisted in the navy and made a career of it and in 1925 he was stationed at the naval air station in San Diego and he retired after 20 years of service in 1935. He was a chief petty officer, his specialty was repairing airplanes that landed and took off from aircraft carriers. On retirement we moved to San Francisco, the reason for that was my mother was born in San Francisco and she still had her mother and father alive and her brother, Warner. That's where my middle name comes from. [laughs]

KM: You have any brothers or sisters?

AO: I have one sister who died a year ago. Her name was Evaclaire.

KM: You tell us a little bit about grade school and high school?

AO: Well I was going to get to that. But I'm not used to giving interviews. When we moved to San Francisco I was 10 years old. We moved into the top floor of a two story flat which just happened to be right next to the San Francisco Public Library. By the way I was sent to a Montessori Kindergarten and there I learned how to read and write even when I graduated at the age of 6.

KM: Graduation, right.

AO: Well I don't remember that. But when I enrolled in grammar school because of my accomplishments already, they put me into second grade so I was one year younger than everyone else in class and this colored my personality. I was always the last to be chosen to play baseball or whatever.

KM: You learned that – that happened at an early age, huh?

AO: Yes.

KM: That's very nice though.

AO: The…let's see where were we?

KM: Grade school and high school.

AO: I'm in San Francisco. The 30s in San Francisco was when the well known bridges were built. The San Francisco Oakland Bay Bridge and the Golden Gate Bridge which went from San Francisco to Marin County. My Uncle Warner used to take my sister and I on hikes and the first day the bridge opened it was for pedestrians only, that was in 1937, and so on the first day it was open, we walked across the Golden Gate Bridge. It's a beautiful thing to do but that day it was all pedestrians, no cars.

KM: What a nice event.

AO: Naturally I took an interest in bridges and I probably had all the bridge books in the library out. I only had to carry them 50 feet.

KM: Let me ask you this, you're talking about the bridges, did you see some of the construction that was going on as well?

AO: Oh absolutely.

KM: Ok, that's not too far where…I mean you could view it from where you lived or over there?

5:00 **AO:** Well after the war was over my parents bought an apartment house, 12 apartments 5 rooms each. That address was on 216 4th Avenue which is fairly close to the entrance to the Golden Gate Bridge. You couldn't walk there or see it from where we lived but that's the Richmond District of San Francisco. After studying all the bridge books from the library I decided I wanted to be a civil engineer when I grew up. I also had music lessons starting around that age, soon as we moved to San Francisco and I studied clarinet and saxophone and I was fairly well talented along those lines. When I got to junior high school which was 7, 8 and 9th grade, I was in the school orchestra, the school marching band and the school dance orchestra. And so that took a lot of my time playing in all those –

KM: At those events.

AO: Those events and I remember when I was graduating from junior high school, it was 1939 when I was graduating from 9th grade. I was a concert master of the school orchestra and we were in the auditorium practicing and the principal of the school sat beside me in a bench seat there and my final report card was sitting on a music stand so he just reached over and picked it up and looked at it and says hey you can't graduate. Why not? Well you haven't had enough physical education classes. [laughs] It's a law that you have to have this many in order to graduate. So he picked out his pen and wrote down that I had taken a particular –

KM: Class.

AO: Class then he said what teacher would you like to have had, so then he forged that teacher's name on my report card.

KM: That's great.

AO: So that's how I happen to graduate from 9th grade.

KM: And that was your best class ever, right?

AO: Yes, indeed. And my parents picked a private school for high school for me, Lick Wilmerding. That Lick is the Lick of James Lick of the Lick observatory. He endowed the school; an industrialist endowed the Wilmerding School. They were originally separate schools but they happen to be on the same block and so they combined them. There was, a block away, a girl's private school called Lux and eventually the three schools became just one, it's known as LWL, Lick, Wilmerding, and Lux. My sister went to Lux; my sister was 2 years older than me.

KM: Was it a day school?

AO: The reason they picked that school for me was because it didn't have a music program. I mean I was so involved in music that I was in private dance orchestras that would go out and perform in gigs and they felt that wasn't a good way to lead your life so they picked Lick, Wilmerding for me to go to so there would be no music. [laughs] And it was probably a good thing that I graduated, as I said already in 1939. I wanted to mention the fact that in 1939 my father was called back into the service even though he had been retired since '35 and the United States was preparing for war and he was sent to the naval air station in
10:00 Corpus Christi, Texas where they trained fliers to land planes on aircraft carriers and things like that. So he was away from home from 1939 until the war ended in 1944-45.

KM: He didn't get home at all during that time?

AO: Only for a one or two week vacation.

KM: Was he based in Corpus Christie during the war?

AO: Yes.

KM: Oh, ok.

AO: And it was very hard for my mother to run an apartment house with 12 apartments, 5 rooms each, and so I had to learn how to do wallpaper hanging, painting, and plumbing repairs and all that sort of thing which was ok but there were still a lot of real estate vacancies in San Francisco on the west coast. Real Estate got very tight on the east coast because of the war in Europe so we had several vacant apartments and a man came in around the first of August in 1941. He was a reporter from an international news agency. He was looking for an apartment, just the kind that we had for his wife and I think he had two children. And so he placed a deposit on an apartment planning to move in September 1st and so that was a relief but he came back the last week of August. He had a telegram from his headquarters that said you are being transferred to Honolulu immediately to cover the Japanese attack on Pearl Harbor.

KM: Wow.

AO: That was in August and that attack was December 7th as you know so I've actually never told this story other than to my friends but I was standing by my mother's side when this gentleman came in our apartment and I was there, this is a firsthand account. My mother began to cry, she'd been trying to get my father transferred from Corpus Christi, Texas to the San Francisco Bay area where there were a lot of naval installations. She began to cry and said now daddy will never come home. And he didn't come home until the war ended in 1945. But the government knew that the Japanese were planning to attack Pearl Harbor. They had broken the Japanese code and all the aircraft carriers were moved out of

Honolulu but they left the battleships there. Nobody knows why but people high up in the administration knew there was going to be an attack on Pearl Harbor and I don’t know to what extent that this is well known history or not but you’re talking to a person who was there when my mother was reading this telegram. She read it out loud.

KM: Did your mother get a chance to go to Corpus Christi to see your father?

AO: No. He was too busy. They were training all the pilots for the aircraft carriers and Lick Wilmerding was a unique school as I already intimated, not merely because they had no music program but they had a fantastic faculty. During the three years of high school I had six courses in physics and the teacher was very inspiring. His name was Ralph Britton and I decided to give up the aspiration to become a civil engineer and design bridges. I decided to become a physicist as a
15:00 result of that. They also had a fantastic chemistry teacher; I think his name was Sidney Vestneys*. I had his course in chemistry the first year at Lick Wilmerding and the first day of class he would hand out to everyone in the class a periodic table of the elements, a photographic copy because during this semester we would have to know the periodic table by heart and that periodic table that he gave me is still in my wallet, it’s been in my wallet since 1939.

KM: All those years. You have it folded up huh?

AO: No it’s about that big and I had plastic put on it not many years ago. Its dog eared at the corners but as a result of that I’ve always known where to look in the periodic table for things I’m interested in. So I graduated from Lick Wilmerding in

1942 and in a way having gone into science – well was very good for me because for a couple of years the United States exempted people studying science from the draft. Eventually I enlisted in the navy because that draft exemption was turned off by Congress. I went to college at the University of California Berkeley, which is just across the bay from where I lived and that was a fabulous university. It still is of course. It was also relatively inexpensive; the tuition per semester was $27 at Berkeley in those days. Not $2700 or $27,000, 27.

KM: Two seven.

AO: Two seven.

KM: Point zero zero.

AO: Yeah, I lived in Berkeley in a boarding house but I would take the bus home on weekends to use my parents' washing machine.

KM: Sure.

AO: As everyone does who lives close enough to home.

KM: What was the campus like when you were there?

AO: It was a beautiful campus, lots of lawns and things like that.

KM: Did you live in the boarding house the whole time you were there?

AO: The first semester I lived with a cousin in Emeryville but that didn't work out very well, it was a very long commute distance so except for my first semester I lived in a boarding house, one block north of campus.

KM: You mentioned enlisting in the service. Were you out of it when you went to college or how did that work out?

AO: Well I went to Cal in the fall of 1942 right after I graduated.

KM: From high school?

AO: From high school. I had a hard time getting in. I flunked the entrance exam to Berkeley but the penalty would be that it'd take some coaching during the summer or take a course your first semester called bone head English; many people had to take it. But the reason I flunked was not that I didn't know English, it's just that we had to write a book report, you know they gave us a list of a few books to read and you'd be surprised which one you had to write a book report on as part of the exam. Well I believed the person who graded my exam just had a different philosophy of life than I did. It was a very well-known book which I no
20:00 longer remember but in 1944 I had finished two years at Berkeley and enrolled in the navy and by doing that I avoided being drafted into the army. So I –

KM: Where were you stationed and what happened?

AO: Well fortunately they had a wonderful new program called the Edey Program. They trained people how to repair electronic equipment so in those days electronics was everything in new warfare. You had radio of course but they also had radar and you had sonar to look for submarines and they even had something called LORAN, long range aid to navigation which is the early equivalent of what we have now.

KM: The satellites.

AO: Satellites, we didn't have satellites then so they had transmitters built at willing countries which sent out pulsed electronic signals which you could use to triangulate, find your longitude and latitude so most people had never heard of LORAN but I was trained to repair and maintain all these electronic devices. It was a very valuable training that lasted essentially a year. I first had to go to boot camp in the Great Lakes Naval Training Station. That took a month or a month and a half. Then we had to go to the pre-electronic school to make sure you know Ohm's Law. That was in Chicago and lasted a month. Then we were transferred to one of several intermediate electronic schools run by the navy and I got to go to the one in Monterey, California. They took over the Delmonte Hotel which is a few miles from Monterey and converted it into an electronics training school and that lasted three months. But then came the big course that took six months and there you really had to be trained in repair.

KM: The nuts and bolts and everything.

AO: Yeah, climbing masts and check on the circuits running the antenna and so forth. Even if the ship is going like this. [gestures] But I spent six months there. The base was actually in San Francisco Bay on Treasure Island. Treasure Island is an artificial island, originally before 1939 it was just part of the Bay but they filled

in…they put in landfill. There's a big, tall island in the middle of San Francisco Bay, it's called Yerba Buena and the suspension part of the Bay Bridge ends on Yerba Buena where there's a tunnel that takes you through to the other side and then there's the cantilever part of the bridge that was built in…I guess it was the 30s also. Now why am I saying – oh well Treasure Island was a landfill island, artificial island built to be the location of the World's Fair in San Francisco in 1939. In those days they used to have a World's Fair in some city, which differed from year to year. They were still having them some years later, there was one in New York and before that my family drove from San Diego to Chicago for the Chicago World's Fair and we stopped off in Iowa to see my father's mother. That
25:00 was the one time we ever saw her but that was obviously when we still lived in San Diego. I don't remember the exact date of the Chicago World's Fair but it might have been in 1933.

KM: Oh, ok.

AO: One or two years before.

KM: The Chicago one?

AO: Yes.

KM: I think it was '33.

AO: '33, yeah that rings a bell.

KM: They had something on the news recently about it.

AO: Really?

KM: Yeah.

AO: Now I know. And so in those days if you drove from San Diego to Chicago it was a real –

KM: It's a real jaunt.

AO: It's a real jaunt. All things break down, they didn't have good tires, and you'd have flat tires often.

KM: It's a long trip.

AO: Yeah I think we got over a leak in our gas tank and they had to put in a new one.

KM: What kind of car did you have?

AO: Well I don't remember. That was my father's car.

KM: Ok.

AO: But where are we now? I stayed in the Navy for two years. I was discharged in 1946 but what happened was after I finished the school on Treasure Island, which was the senior. They transferred me to the Philippine Islands. War was still going on. This was in the summer of 1945, that's right. And to catch a ship to take me to the Philippine Islands, they transferred me to San Diego, there's a naval base in San Diego and the ships that were going to the Philippine Islands left from there. So I was stationed in San Diego temporarily and I went there probably around early august but on August 14, the Japanese surrendered. That made my mother very happy because otherwise war would still be going on. So I ended up being sent to Subic Bay on the main island. Same island that manilla was on but 100 miles or so up the coast. It had been a naval base and there I put into practice all I'd learned. The ships, naval ships, would come in and they'd send us out on a launch to work on their radar gear. There was one ship that came in and the skipper had been skipper since the ship was commissioned and the radar had never worked, never once. And so in 2 days I fixed it, the first time. There were 27 things wrong with it. Probably most of those 27 were caused by previous technicians who didn't know what they were doing, would be my guess. But that was very good duty because the food we got was – you know 15 meals a week with spam. But if you went out to the ship you could have lunch there and they had really good food.

KM: Food was better.

AO: Food was really much better. So eventually I got sent home and transferred to a naval base near Livermore. I don't know whether it was Livermore or not but it was within a stone's throw of Livermore and that's where they gave me civilian clothes and I ended up going home. That was in '46, summer of '46. Is that right? Sounds right.

KM: Did you go back, finish school after that?

AO: Well that's what I did – yes. So in the fall of '46 I reenrolled at Berkeley and in 2 years I got my bachelor's degree and I stayed on at Berkeley for my graduate studies. My aspiration is, you know it switched from civil engineering to being a physicist and they had the most wonderful physics professors at Berkeley then that you could ever imagine. I had courses from many people you've read about in the newspapers for the last 50 years. I even had Oppenheimer for one of my courses. Weiskopf for another, Pinofsky for another. All were very extremely famous people and I did very well in school. My aspiration was to become a theoretical nuclear physicist, that's what I wanted to become. There were four theoreticians on the faculty when I entered graduate school in '48. And all four of them were in theoretical nuclear physics. That was a very booming subject at that time and I was accepted as a graduate student by Professor John Carlo Wick, an Italian who had made many important contributions to theoretical physics at the time and I began studying with him. It began by reading the right books, not doing any research yet. But then 1950 came along and this was a great disaster for the University. The regents of the University of California decided to impose a more strict loyalty oath on all its employees and faculty. It's known as the year of the oath. And you either had to sign the oath or be fired. Well all four theoretical physicists signed the oath and then resigned their professorships in protest. They were insulted by having to sign a loyalty oath. And all of our – all of the graduate students in theoretical physics were left as orphans. They had no one to work for. I mean these four theorists were very good. The four institutions they got jobs at instantly were Columbia University, Carnegie Institute of Technology, Bell Telephone Laboratories, and – what was the last one? Oh the University of Illinois in Urbana. So of course the physics department decided to look for theorists who would be willing to come and sign the loyalty oath. And they had to work long and hard for that but they finally found a person in December of 1950 who said he'd be willing to come but he was currently employed at Bell Labs and busy on certain projects and he said he couldn't come until July 1, 1951. Now he agreed to take on five graduate students.

KM: Which you were one of them.

AO: No I was not one of them. I mean there were seven or eight orphans and I don't know how he decided which ones to take but I was not included. So I was very sad because there were no other theorists there to supervise my work. I decided to go up to my office or somewhere in the physics building. I took the elevator, which I never did. I would always walk up stairs instead of taking the elevator but I was feeling so blue I took the elevator. Well the elevator stopped at the next floor up and Prof. Loeb stepped in. Now I had taken several courses from him as an undergraduate and I did very well in them. He was a specialist in electricity and magnetism and during the war he was in the navy, a flag officer in the navy. He was in charge of demagnetizing all the ships in the Pacific. But anyway he looked at me and said you look sad, what's wrong. Well I told him what was wrong and I got a note from him the next day saying go see Kittel. He's agreed to take you on. Now Kittel was a solid state theorist, not a nuclear theorist so that's how I became a theoretician who worried about solids, condensed matter, but he was going back before Christmas to Bell Labs and wouldn't be back until July 1 so he called me in and told me about electron spin resonance and it'd become a very popular subject the preceding three or four years. Lithium is a simple metal and one of the professors at Berkeley had looked for the conduction electron spin resonance with him and couldn't find it which was a puzzle. Either the experiment was wrong or the relaxation time of the lithium spins was too short so you couldn't see it. So he assigned to me as a thesis project to find all the mechanisms by which lithium spins can relax. In other words if you get them out of equilibrium they come back to equilibrium with a certain characteristic time, it's called the relaxation time and that was the first time I saw Kittel as my thesis advisor. The second time I saw him is when he came back on July 1 and I told him that I thought I'd finished everything he wanted me to do. Well what he did was what he never would have done later in his career; he said oh in that case you'll need a job. And so I ended up getting a post-doc job at the University of Illinois in Urbana. I was hired as a theorist and Illinois had become one of the best departments in the country for solid state physics that had been built up by Fred Seitz. I went there to do theoretical work but the radiation damage project was what I was working on. They had atomic energy commission funds to support this research. Radiation damage is important in the design of nuclear reactors because the flow of neutrons and protons damages the metallic things that hold the reactor together. Well I couldn't think of any decent theoretical problem to work on in that area. I said what the world needs are facts, not theoretical speculations. It was a rather new field and so I spent my two years as a post-doc at Illinois doing experimental work which I devised by myself and carried out by myself which was rather good work as a matter of fact. When the metals are irradiated with neutrons and protons, atoms get knocked out of place. They have to somewhere so they go to interstitial sites in the crystal leaving a vacancy behind. So when those – the first year I studied the motion of interstitials and vacancies as they diffuse around, that's a function of temperature and the second year I spent measuring the heat that they liberate when they annihilate one another. Remember that a vacancy is just made by knocking an atom out of place leaving a vacancy behind. They try to find one another once again and give up some heat so I developed a thermal technique to measure the energy liberated when the interstitials and vacancies recombine. One thing this device would do which of course I didn't know is if you do something new, you should give it a name. Well I never gave a name to what I was doing. If I were to name it today I'd call it differential scanning calorimetry. It's used extensively by physical chemists studying chemical reactions but the inventor of this differential scanning calorimetry, if you try to Google it; turns out to be some paper that was published 11 years after mine. You have to give things catchy names. Let's see where am I? Well after two years as a post-doc you have to get a permanent job and I interviewed in a few places, got a couple offers and I took the one to Cornell University.

KM: Let me ask you, were you married at that time?

AO: I'll go back and tell you what happened the day that I talked to Charlie Kittel for the second time. He told me I – he asked me what sort of job I wanted and I said I didn't know so he had me sit down next to his secretary and went in to his inner office. He came out five minutes later and said Fred Seitz just hired you if you're willing to live in Illinois. I said sure. [laughs] So that was the easiest way to get a post-doc job. Now Fred [inaudible] is one of the fathers of solid state physics. In 1940 he wrote a book, a big fat book on the modern theory of solids. He built up the solid state physics at Illinois and when he left Illinois many years later he became President of the National Academy of Sciences. Served eight years in that position and then he became President of Rockefeller University, very, very distinguished scientist. One of the best I've ever known. So that's how I got my first job as a post-doc. And that evening I was walking across campus with an acquaintance and I had a great idea. I said would you like to live in Illinois? Now then in the culture of those days, that question was only a proposal of marriage and the girl involved was Margret and 58 years later she's still by my side as you can see. So the wedding was in August, you know about four weeks after that, August 25. So that answers your question. Now one thing that happened while I was at Illinois, I was doing experimental work because I didn't think any really good interesting problems in radiation damage theoretically. On the other hand the University of Illinois had become a hot bed of magnetic resonance. There was Charlie – in physics there was Charlie [inaudible], Dick Norberg [?], Mark [inaudible], and Walter Knight. And in chemistry, Herb Brown. These are all very well-known names in the field so they had an interesting seminar going every week on magnetic resonance. Since I'd never gone to a seminar in magnetic resonance before you know I did my thesis in essentially six months and read a little bit about it but I bootlegged going to the seminar and Dick Norberg [?]

mentioned in one of the seminars, he was in fact giving, that there is information to be found in the free induction decay, that is when you knock a spin system out of equilibrium. The free induction decay is when it tries to get back into equilibrium. Well I went home and thought what's going on in the free induction decay and it's – you got a medal there, this case if it were lithium, that it's trying to relax back to its equilibrium state and one of the mechanisms – I studied five different mechanisms that would cause such relaxation into equilibrium, and one of them was the least important of all, namely the interaction with nuclear spins. Nuclei have – are high little gyroscopes too as well as electrons so I wondered what would happen to the nuclear spins when the electrons spins were out of equilibrium. Now if your cleaver you can knock the electron spins out of equilibrium by a percent or so and I calculated what would happen as I already intimated, what would happen to the nuclear spins. Well instead of being knocked out of equilibrium by one percent because of their interaction with the electron spins, they were knocked out of equilibrium by a factor of a 1,000. In other words by exciting the electron spin resonance you can enhance the nuclear spin polarization by a factor of 1,000. I did the calculations several times to make sure that I did it right and I did. I got the same answer every time and I then showed Charlie [inaudible] one of my colleagues who was in magnetic resonance what I had found out. It was a complete surprise, no way you could have predicted by intuition that if you disrupt one part of the system by 1%, the other part of the system goes up by 10,000%. It was just an enormous effect. And Slicker [?] followed the argument that night and decided the he believed it so we took a new graduate student, and they decided to build apparatus which you could actually do such an experiment where you – it's a double resonance experiment where you have one oscillator that works on the electron spins and another oscillator that works on the nuclear spins. Well this involved technology that didn't exist yet. So it took them about a year and a half to build the apparatus. It hadn't been built by the time I left Illinois, where they were doing this. And a few days after I got to Cornell University, Margret and I were looking for a house to live in, I got a telegram. The secretary stuck a telegram…or stuck a note saying you have a telegram. Well that frightened me very much because if you may remember in 1950 if you got a telegram if was because somebody in your family died. But I finally got courage to go pick up the telegram and it was a telegram from Charlie Slicker [?] said the first time we tried the experiment it work and agreed exactly with what you had predicted.

KM: Very good.

AO: Yeah well that was consoling for a special reason. I talked about this phenomenon, which I predicted theoretically at the Washington meeting of the American Physical Society in 1953. I was still at Illinois at the time and I had a ten minute talk that was scheduled in a magnetic resonance session and sitting in the front row at the session were the four biggest names in magnetic resonance. All four of them have Nobel Prizes. There was [inaudible] Block from Stanford, there was Norman Ramsey from Harvard, there was Ed Parcel from Harvard, and – who was the fourth one? Parcel, Block, Ramsey, and Robbie.

Robbie from Columbia University and after my ten minute talk the chairman of the session who was surrounded by the other three was Ed Parcel and he got up and said we think your evaluating the second law of thermal dynamics. I decided I didn't want to argue with those guys so I just said I don't think I have, let it go at that. But here were the four stars in magnetic resonance you know disbelieving it. I also sent a preprint of the paper I was about to write to Charlie Catell. And what I'm saying now I know because the story was told to me by a friend of mine who at the time was a roommate with George Fair. George Fair was a new graduate student at Berkeley at the time. He was starting to work for Catell and Catell gave him the preprint of my paper on this dynamic nuclear polarization and said study this paper and give a seminar in a few weeks but be sure to find the mistake. Well he didn't find any mistake but that phenomenon is what in the field is known as the Overhauser Effect. And it has been applied in a number of ways now and it is an effect which allows people to determine the structure of proteins and other biological molecules. There was several books written on that but you mentioned in your – that you wanted me to discuss –

KM: Just make a comment if you'd like. You talked about it already I think. Covered how it came about.

AO: Yes. That was an exciting thing to have happen.

KM: 1953 is also the same year for the double helix, right? Watson and Crick, the DNA...

AO: They were around there, I guess. But the deepest work I've ever done – you know some things take a long time some things happen very quickly the discovery of dynamic nuclear polarization took me two days if not just one afternoon. I didn't show it to Slicker until I'd done it several times. But I want to tell you about the work in neutron interferometry. This happened – well it began in 1965. I was still at the Ford Motor Scientific Laboratory where – I'd left Cornell to go there. They were building a new scientific laboratory and the person who was going to be manager of it was a very persuasive person and all my friends told me don't pay any attention to him, those are all lies. But it turned out that all the lies turned out to be true. And it was the best research environment I've ever seen on the surface of this earth for – I stayed there 15 years. I left Cornell after five and it was an ideal move for me to make. But one of my colleagues at the Ford Laboratories was Sam [inaudible]. He had recently got his PhD in neutron diffraction. They had a little research reactor at Ann Arbor at the University of Michigan. In the middle of 1965 a paper appeared in Applied Physics Letters which I didn't see, I didn't read that journal. Sam [inaudible] saw it and called me into his office. He said Bons and Hart [?] have built and x-ray interferometer and they describe how it functions in this little paper. Then he said what do you think we could do if we used it for neutrons. If we had a neutron interferometer? So we agreed to get together again two hours later and he had dreamed up an experiment, instead of using x-rays sending through the neutron to the interferometer, send neutrons through. He said you know one of the very mysterious things about elementary particles, if they have [inaudible] is if you rotate the particle spin direction by 360 degrees, were talking about the world of wave mechanics. Things happen because they are being described by wave motion and that's quantum mechanics is essentially wave mechanics. But if you rotate the spin of a particle by 360 degrees you don't get back the same wavelengths you started with. It has changed sign by a factor of – it's a changed sign. There's a minus one that comes in. Very mysterious, this was discovered by [inaudible], one of the real giants of 20th Century physics and so in an interferometer you have a beam coming in and you break it into two beams and then bring them back together again and where the two beams that had been broken apart then can interfere and if they had the same distance from there to there the interference would be – you'd double the size of the wave function. They were – one is shifted by 180 degrees then the two out here cancel out. And so he had thought up this two pi precession experiment as it was called. That's a possible application of a neutron interferometer. And I'd come up with a different idea, you have a neutron beam come in, breaking up the two, coming back together and interfering but suppose you rotate it about the beam by 90 degrees. So instead of going this way they went this way. Well one goes up and the other goes down. There could be an effect of gravity on the interference and I predicted that if you had a neutron interferometer working like that, if you rotated the whole thing about the beam the intensity of the beam coming out the other end would go up and down enough times to make an feasible experiment. So the idea of that experiment took exactly two hours. Now the people who wrote the paper, Bons and Hart, said that this interferometer wouldn't work unless the interferometer crystal has to be out of a perfect crystal of – and they had used silicon, had to be absorbing. Now x-rays are strongly absorbed and they claimed that's why their experiment worked. They could make x-rays interfere with one another but silicon doesn't absorb neutrons so according to Bons and Hart, neutron interferometer made out of silicon wouldn't work. Now silicon is used for these things because one could then buy large single crystals of silicon where every point of atoms is exactly in the right place and that's necessary for the interferometer to work. So we – there's another semiconductor called indium antimonide. Indium absorbs neutrons very strongly so we bought the finest indiums antimonide single crystal that was available on the surface of the earth but didn't work. It wasn't perfect enough, in other words you couldn't grow any antimonide single crystals the way you could grow silicon. So we let that idea lay dormant, that was in 1965 but then I came to Purdue in 1973 and the spring of 1974 Roberto Carlo was entertaining at his home at a party for this seminar speaker and I think the seminar speaker was in the field of x-ray diffraction and I told him about the two [inaudible] experiments that could be done if only we had a single crystal of indium antimonide to make a neutron interferometer out of. And Roberto overheard that remark and said what's wrong with silicon? I said well it doesn't absorb neutrons. He said well it doesn't have to but that's what Bons and Hart said it had to. He said they were wrong. And Roberto was one of the world's experts on the dynamical theory of diffraction. He convinced me that the experiment could be done with silicon. So the next week we went to the head of the physics department who was Earl Fowler at the time and told him about this experiment. He authorized to spend up to $10,000, something like that to build such an interferometer out of silicon. Silicon is a very hard material, the only thing that can cut silicon is diamond, you have to use diamond saws made out of little silicon chips to cut silicon and so Roberto build an interferometer out of silicon and surprisingly it worked the first time with x-rays. You could see that it was acting according to the principles of [inaudible] for x-rays and so all we had to do was find a way of mounting the interferometer so one could rotate it smoothly and if you rotated the silicon crystal by just a few degrees the interference went away and we assumed that the – well I assumed that the interference went away was because the large single crystal silicon – I brought a picture. Here's the interferometer that we first made and here are – the beam comes in the first ear, splits it into two beams, the second ear directs the two over to the third one and they –

KM: Brian should he hold that up a little bit?

AO: And that interferometer was put into a box with apparatus for rotating and neutron counters and things like that but we couldn't rotate the interferometer without losing the coherence. This was built out of a cylinder of perfect silicon which in the semiconductor could provide in those days. We just had a piece of metal with a v grove in it and just set the interferometer down in the grove being held there with its own weight. And that didn't work. So I tried the following thing, I went down stairs at home to our pool table and cut some of the green felt from the skirt of the pool table, made two green strips and put the two green strips between the interferometer and the metal and then studied how fast we'd lose interference as a function of how far apart the felt strips were. You know the felt were too far apart it could sag just a little bit in the middle, put too close together it could sag at the ends. And so we were able to find that separation between the two felt strips so that we could rotate the interferometer 20 to 30 degrees and so we – Sam Warner got back into this experiment by designing the neutron. Roberto and I were not familiar with neutrons so Sam puts together all this stuff here up at Ann Arbor and so we took the interferometer up to Ann Arbor and did the experiment. And it worked the first time because you know 8 or 10 oscillations and the rotation from -20 to 20 degrees. Now this is a very deep experiment because gravity as you may know controls how stars move and planets move and asteroids move. Gravity is an extremely weak force, you divide electric forces by it, one followed by forty zeros and that's how strong gravity is. Whereas quantum mechanics works on things that are atomic dimensions and this is the first experiment in the history of physics where the outcome depends on both planes constant and the gravitational constant is the only other one. What we proved is that you have to put the gravitational potential into the Schrodinger Equation which is what quantum mechanics is all about. And that was back in 1975 when we… So 35 years have gone by and there's still no other experiment in physics which involves simultaneously gravity and quantum mechanics. In other words we proved that the gravitational potential has to be put into the Schrodinger Wave Equation and no one has ever done that. But we also [inaudible] did this other experiment about rotating the spin of the neutron 360 degrees in the relative phase acquired a factor of -1. Interesting story I like to tell in that connection is I was giving a colloquium at MIT on the interferometer experiments and at the end of the colloquium Victor [inaudible] I don't know whether you ever heard of him, he was a professor at MIT, he was director of big laboratory over in CERN in France I guess it is for many years. He was there, after my colloquium he got up and came to the podium, looked out into the big auditorium filled with graduate students and faculty, said I have a confession to make. He said I never believed in that factor of -1 until today.

KM: That's very nice.

End of Interview

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*Proper names may be spelled incorrectly