

# A RANDOM WALK THROUGH SPACETIME

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## **Physics for a Living**

I never cease to be amazed by the fact that I was paid to do Physics for a living – a subject that deals in a fundamental way with all aspects of the physical universe. Its scope is unlimited. The topics studied range from the motions of the great galaxies on the one hand, to the motions of minute quarks in nucleons on the other. The energies involved range from those associated with explosions of supernovae to the near-zero energies associated with the behavior of systems at temperatures close to absolute zero. As children, we are inquisitive about all that goes on around us, and we are often mystified by what might be beyond our immediate world. Physicists attempt to provide quantitative answers not only to our childhood questions but also to the many profound questions concerning the nature of things that we continue to ask throughout our lives. Physicists are gadgetiers with a flair for mathematics.

It is a remarkable fact that very few fundamental laws are required to understand and explain the behavior of all physical systems so far studied. This is a most fortunate situation – we would be lost if there were different fundamental laws needed to explain all the different phenomena in the physical universe.

## **The Early Years**

I was born in 1930 in a room over my grandfather's bakery in the East End of London. It was a time of economic depression, grinding poverty, work houses, and labor unrest. My father worked in the family business as a pastry cook. Before my second birthday, we moved to nearby Bow where my parents took over running a bake-house and shop, owned by my grandfather. My earliest memories include men – blind and crippled – slumped against the warm outside wall of our bake-house. They were the forgotten warriors of the Great War, a war in which almost one million Britons lost their lives, and one-and-a-half million were wounded.

My parents never stopped working. We never went on holidays, except for a brief visit to the east coast in 1938. There were no books in the house. My brother and I led self-contained lives. I carved wooden boats, built cars and airplanes, and did numerous drawings and paintings. I wrote stories and poems. My time was fully occupied. I attended the local school where I was fortunate to do well.

## **The War Years**

My early life changed dramatically on September 3, 1939 when Great Britain declared war on Germany, following the Nazi invasion of Poland. Along with hordes of other children, we were evacuated from the inner city to the relative safety of the countryside. For the next five-and-three-quarter years, I lived with foster parents.

In the summer of 1940, I returned to London and, in early September, the blitz began. We avoided the local devastation by living and sleeping in the cramped space of a nearby Anderson shelter. It was again time to leave, and I was sent to the West Country to a village high in the Mendip Hills, not far from Cheddar. My new mother was a schoolteacher. She had never been married, and was pleased to have an adopted son. This random happening had a lasting impact on my future. She introduced me to many books, and she encouraged me to focus my attention on learning, in general.

For the first time, I saw mountains, streams, and crystal clear ponds, filled with crested newts. We were reminded that there was a horrendous war going on, not far away, when enemy bombers could be seen trapped in searchlight beams as they made their way above the Bristol Channel towards the Avonmouth docks where they dropped their dreaded bombs, lighting up the sky for miles around. On one occasion, a German plane was shot down, and crashed in the hills, several miles away. Everyone in the village rejoiced; at the time, we were all conditioned to believe “the only good Germans are dead Germans”.

The village school had two rooms, and there were two teachers. One teacher taught children ages 5 to 8 and the other taught the 8 to 11-year-olds. One morning, I arrived at school and was given a set of questions to answer. It was the “11-plus” examination, later abandoned. Without preparation, I had to answer problems in arithmetic, grammar, and I had to write an essay. I recall that I thought this unexpected event to be a fun day. At the time, fewer than 20% of all children in England passed the exam that was set to sample the “intrinsic” abilities of all candidates. I was one of the two students to pass the exam in the village school, and I was therefore given the golden opportunity to attend a grammar school for the next seven years. It was my chance to escape from my generations-old family baking business.

My local school in London was the Coopers’ Company’s School, founded in 1536. It was the leading grammar school in the East End, and happened to be evacuated to the town of Frome in Somerset, about 30 miles from my village home. I packed my belongings and traveled the short distance to my new school. It was a place known for excellence in teaching both the Arts and the Sciences. My new foster parents were chosen randomly; I was again fortunate to have not one but both parents who were teachers. Their interest in my development, and their general guidance, were critically important to me.

In several subjects, including Mathematics, I was taught by the last of the Victorians. They were masters who had been at the school in the 1890’s, and were brought out of retirement to take the places of those young masters serving in the armed forces. Their frequent and unjustified uses of the cane instilled a sense of fear in all students; we were Dickensian boys.

On July 19, 1945, following the end of the War in Europe, the boys of the Coopers’ Company’s School left their foster homes and returned to London. The utter destruction of many parts of our East End was overwhelming. It was difficult to settle down with my own family in a strange city.

The schoolwork was most demanding. We had no choice in the subjects that we took – they were determined by the requirements of entrance into Universities. At my matriculation examination in the summer of 1947, I took all the standard subjects including French, Latin, English, English Literature, Mathematics, Physics, Chemistry, and Art. Luckily, I did well, especially in the Languages and Art. Normally, a student with my credentials would continue in the Humanities. Instead, I continued my studies in the Sciences, taking Pure and Applied Mathematics, Physics, Chemistry, and Art. I passed the Higher School Certificate of the University of London in the summer of 1949. It was my intention at the time to go to University and study Mechanical or Electrical Engineering. I had no thought of doing Physics!

### **The Royal Air Force**

My immediate plans were changed when I was drafted into His Majesty's Royal Air Force. I arrived at a notorious square-bashing camp called Padgate near Warrington in Lancashire. It was a prison-like environment, totally different from the idyllic setting of the Coopers' School. I had been launched into the real, adult world. At the end of my basic training, I was posted to a camp in Wiltshire to learn how to service airborne electronic equipment, particularly receivers and transmitters. In June 1950, I was sent to the Royal Air Force Flying College at Manby in Lincolnshire where, as an Air Wireless Mechanic, I serviced and installed equipment in the last of the operational propeller-driven bombers – the legendary Halifaxes, Lancasters, Lincolns, and Stirlings.

Shortly before I was to be “demobbed”, the Korean War broke out and my service was extended for another six months. By good luck, I was too near leaving to be sent to war. My friends who were a few months younger than I were not so fortunate.

### **A Physics Apprentice**

I returned to civilian life at the end of 1951, and went to live with my parents while looking for a new job. The year before, they had sold their business in London and had opened a bakery in the Thames-side village of Pangbourne about a dozen miles from Oxford. A major government research laboratory – the Atomic Energy Research Establishment – was located near the village of Harwell, about 15 miles from Pangbourne. I found a local advertisement for Experimental Officers (a fancy name for laboratory assistants) at Harwell. Positions were available in many of the Divisions at the center, including Electronics, Reactor Physics, Nuclear Physics, Chemistry, Medical Physics, etc. I went for an interview, hoping to join the Electronics Division following my Air Force training. The interview went well. I was asked to design electronic circuits, and to answer questions of a general nature in Mathematics, Physics and Chemistry. At one point in the interview, a member of the committee noted that I had played rugby for the Royal Air Force Flying College. The discussion then turned from science to rugby. I had been a “fly-half” – a position not unlike that of quarterback in American football. This rare qualification turned out to be critically important; three weeks after the interview, I was appointed an Assistant Experimental Officer and the week after, I was playing rugby for Harwell against the Royal Aircraft Establishment at Farnborough.

I was assigned not to the Electronics Division but to a position in the Electron Accelerator Laboratory to repair and develop electronics for experiments in Nuclear Physics, and to assist in setting up and running experiments. I had a great deal of learning to do; Nuclear Physics was an unknown field to me. It was clear that the knowledge of Mathematics and Physics that I had acquired in Grammar School (having studied the subjects for seven years) was sufficient to read and understand many of the new concepts that I had to deal with. My evenings and weekends were spent studying the standard works in the field. I recall that, at the time, a key work in Neutron Physics was an article in the *Reviews of Modern Physics* written by a youthful Bob Adair.

In addition to running and repairing the electron accelerator, I was involved in building apparatus for the experiments, and in collecting and analyzing data. I was a physics apprentice.

In the summer of 1952, the Administrative Officer of our Division sent a note to all members that three new houses were available for those getting married in the next month or so. If there were no takers, the allotted houses would be given to another Division. I had met Pamela in late 1947 at a dancing class held between girls of the local Coborn School and the boys of Coopers. We were engaged, and I called her to say that if we got married in the next few weeks we would be able to move into a brand new Harwell-sponsored house in Didcot. The rent would be 39 shillings and 10 pence per week. We were married in South London on September 11, 1952.

At that time, I was busy decommissioning the electron accelerator in preparation for the delivery of a magnificent new accelerator; it was the most advanced electron machine in the world. The Mullard Company, a branch of Phillips Eindhoven, had designed and built the accelerator using highly innovative techniques. It was not simply a machine for doing Neutron Physics; it was the prototype for a new series of electron accelerators to be installed in English hospitals for Radiation Therapy. The first was to be installed at Hammersmith hospital in West London.

I helped install the new machine, and a few months later, we were doing experiments that were highly competitive with those being carried out in the U.S. and the U.S.S.R.

#### **Further Education**

The Government was aware of the fact that many of the Experimental Officers at Harwell were well qualified for entrance into Universities. A program was therefore introduced that encouraged them to take external degrees, offered by the University of London, at the Oxford Polytechnic. Full support was provided for one day of classes per week, for three years. I enrolled in the program in September 1953. It was a most challenging experience. We took classes in Physics (including laboratory work) and Mathematics from 9 a.m. to 9 p.m., completing the normal three-year program for internal students in three years of part time study. There was no building-up of credits in a subject – the final degree examination, held at the University Examination Halls

in London, covered all the material taught over the three-year period. In 1956, I took the examination and fortunately passed. In addition to completing the degree, and working at the accelerator laboratory, I had become a father, and I had written my first research paper. 80-hour work-weeks were the norm.

I decided that this was just the beginning of a career in Nuclear Physics. In 1958, I took the demanding Graduate Examination of the Institute of Physics in London. I had prepared by self-study. There were 86 candidates from all over England, 25 passed, and I was the only one to be successful by self-study. A few months after this success, I was promoted to the rank of Senior Scientific Officer.

I was now in a position to carry out independent research. I had several Experimental Officers working under my supervision. In the next two years, I published six papers.

### **The Oak Ridge National Laboratory, TN**

In late 1959, the U.S. and U.K. Governments introduced an exchange program for one Nuclear Physicist from each country to cross the Atlantic to do research, and to take in and give out technical information. The highly eccentric Dr. Egon Bretscher, Head of Nuclear Physics, called me into his office to say that I had been selected to go to the Oak Ridge National Laboratory in Tennessee in 1960 as the representative of Harwell Nuclear Physics. This was a great opportunity for me to develop my research in ways not possible in England.

My family and I arrived in Oak Ridge in midsummer. It was steaming hot and humid. Oak Ridge was a government town, infamous for developing and manufacturing the separated isotope, uranium-235 for use in the atomic bombs that destroyed two great Japanese cities and their inhabitants. The main cinema in town was segregated. The town of Clinton was just a few miles from Oak Ridge. "The Clinton 12" had received international attention for their courage as the first black students to attend the High School in Clinton. I was aware of the bombing of the Clinton High School in 1958 (attributed to members of the KKK), and I was surprised to learn that Clinton students were still being bussed to a school in Oak Ridge. This was a shock introduction to life in a Southern State at the time. It was particularly incongruous to have these tragic happenings going on within ten miles of one of the great research centers in the world – a center filled with highly educated, thoughtful and compassionate people. I later learned that many of my Oak Ridge colleagues had been, and were, actively involved in the Civil Rights Movement.

I was most fortunate to share an office with Jack Harvey, who, with his colleague Don Hughes had, in 1958, shown that the two most important statistical distributions in nuclear structure – the Wigner spacing distribution of adjacent resonances, and the Porter-Thomas distribution of the neutron widths (lifetimes) of the resonances – were consistent with the limited observations then available. These distributions now form the basis of the burgeoning field of Random Matrix Theory in Pure Mathematics. By 1959, Michael Moxon, Eric Lynn and I had carried out the most extensive tests

of both theories, and had established their correctness beyond a shadow of doubt. Random Matrix Theory is used in understanding subjects as diverse as Stock Market fluctuations, String Theory and Quantum Gravity. In the mid-1950's there were fewer than ten persons in Britain who were directly involved in the study of random matrices. The main interest in Nuclear Physics at the time had to do with nuclear structure. Those of us studying the statistical properties of nuclei were considered to be a fringe element. The subject of nuclear structure is no longer a major branch of the field whereas the understanding of the statistical properties of nuclei continues to lead to major advances not only in Number Theory (including the challenging problems having to do with Primes) but also in the vast field of Chaos Theory.

Three weeks after my arrival at Oak Ridge, an international conference on Nuclear Physics took place at Kingston on Lake Ontario. I had submitted two papers to the conference, and therefore I applied to the Harwell authorities to provide me with some funds to attend the meeting; they did not provide one cent. I drove to Canada in my right-hand drive Hillman, taking with me two Oak Ridge colleagues, who helped fund the trip. This was a most important time for me. There were three Nobel Laureates at the meeting, and many other luminaries from around the world. A youthful Allan Bromley, then a Senior Scientific Officer at Chalk River in Ontario, had organized the conference; not surprisingly it was run with military precision. My new office mate, Jack Harvey gave the review talk on the status of Neutron Physics and he used my data, that I had given to him just days before, to illustrate the current state of the art. Following the publicity given to my research in the U.K., I was interviewed by Leonard Parkin, a reporter for the BBC. He was surprised to see how young most of the conferees were. I pointed out that it was the most fashionable branch of Physics at the time, and therefore attracted many youngsters to the field. I met Allan Bromley; he had just decided to accept an offer from Yale to come and set up the Nuclear Structure Laboratory. The Mayan temple on the corner of Whitney and Edwards is a permanent reminder of his many contributions to Yale and Country.

I worked at the Oak Ridge high-flux reactor, and the 3 million-volt Van de Graaff, a unique facility with a beam of charged particles that could be pulsed to last for a mere 3 nanoseconds. The benefits of the exchange of ideas were amply demonstrated when I was able to continue my earlier work on glass scintillators for neutron detection by making use of the fact that Oak Ridge was the center of the Western world's supply of the isotope lithium-6. (It is used in the nuclear reactions associated with the hydrogen bomb). I obtained 1 kilogram of pure lithium-6 carbonate, available nowhere else, and took it to the leading scintillating-glass manufacturer who happened to be at the Naval Research Laboratory in Washington DC. In two weeks, Bob Ginther, the expert, had produced the very first useful piece of scintillating Li-6-loaded glass, and I was immediately able to test and use it in experiments at Oak Ridge. I have the original with me. These scintillators are now used worldwide as the neutron detectors of choice at energies below several hundred thousand electron volts.

Oak Ridge was one of the leading centers in the world for designing and using research reactors. The authorities were planning to build a very high-flux reactor for fundamental research in Neutron Physics, Solid-State Physics, and Medical Isotope preparation. It was clear from our work at the Electron Accelerator Laboratory in England that the future of Neutron Physics was clearly in the field of Accelerator Physics and not in Reactor Physics. I therefore gave a series of lectures on the fundamental theory of electron accelerators, and a review of what had been accomplished with them and, more importantly, what could be achieved in the future. After several lectures, I found that there were many scientists at Oak Ridge interested in pursuing the idea of installing an electron machine in a new laboratory. A small group of us therefore drafted a proposal for a world-class accelerator facility that would put Oak Ridge in the forefront of the field for decades to come. I did the bulk of writing the proposal, and recommended that the laboratory ask the Government for \$9,000,000 for a state-of-the-art machine and laboratory space and equipment. The Head of the Physics Division announced that I was the most expensive visitor that had ever been to Oak Ridge! Before leaving for England, several of us toured a possible site for the new facility and found a promising piece of land close to the existing main Physics Laboratory. After returning to England, I learned that the first proposal had been rejected because the cost was too high. The second proposal reduced the cost to \$6,000,000 and was instantly funded by the Atomic Energy Agency. The new machine, called ORELA (Oak Ridge Electron Linear Accelerator), was completed in the late 60's, and for the next 30 years was the preeminent neutron facility in the world. At the present time, the laboratory is struggling to obtain sufficient funds to keep it operating at full power.

#### **In Full Flight**

During my year in the U. S., a new electron accelerator had been commissioned at Harwell. It had a greatly increased energy, and could accelerate a very large current. Having learned to deal with pulses as narrow as a few nanoseconds while at Oak Ridge, I immediately set about designing and constructing a new injector for the electrons entering the accelerator. In the space of a few months, I had built a device that produced electron pulses each 5 nanoseconds in duration. This opened up a new area of research, particularly in a field known as Nuclear Photodisintegration. The reaction involves the most important collective motion in nuclei; gamma rays with energies of about 20 million electron-volts have wavelengths comparable with the size of a typical nucleus. The electric field of the gamma ray separates all the charged particles in the nucleus (the protons) from the neutral particles (the neutrons). The two groups are coupled by the intense nuclear force that causes the two groups to oscillate, collectively, with a frequency characteristic of the particular nucleus being studied. This phenomenon is known as a giant electric dipole resonance, a topic favored by theorists because the fundamental interaction is so well understood. A visiting Harwell Fellow from Australia joined me in this work and, by February 1962, we had improved the energy resolution

of all existing work in the field by a factor of 100. My colleague returned to Australia in the late spring, and I was able to exploit our new technique.

In September 1962, I went to a conference at the University of Padua to present my latest results. A delegation of physicists from Yale attended the conference. Among the delegates were Professors Gregory Breit, Allan Bromley and Charlie Bockelman. They were giving papers on their latest work in the field of Heavy Ion Physics. I happened to sit next to Charlie Bockelman at a conference luncheon, and quite unexpectedly, he asked if I would be interested in coming to Yale to set up a program of research in Photonuclear Physics using their new high-powered electron accelerator. In a shocked state, I thanked him, and said that I would give the matter some thought. A year later, I was invited to review the field of research using electron accelerators at an international conference held at the old Somerset Hotel in Boston. The speaker before me was Allan Bromley, who reviewed the field of tandem Van de Graaff physics. I met him after my talk, and he asked if I was interested in coming to Yale; he had been talking to Charlie Bockelman. Again, I did not commit myself. In the spring of 1964, Allan and I met once again at a conference in Paris. One evening, we were boating down the Seine with all the conferees, enjoying the food and wine. Allan chatted to me, and asked when I would be coming to Yale. I said, there and then, that I would come in 1965, on condition that Goldwater was not elected President!

**At Yale: Further Education, Research, Teaching, and Administration**

We sold our new home in Newbury, Berkshire (a home that I had designed), packed all our belongings, and set sail for the New World. Within two weeks, we had bought a house in Hamden, our sons were registered in school, and I began work at the Electron Accelerator Laboratory as a Senior Research Physicist. Although I had no formal teaching responsibilities, I did, in fact, teach a graduate course in Nuclear Physics and a recitation section in Bob Adair's undergraduate course – all for free!

For many decades, the members of the Physics Department at Yale had been leaders in the development of particle accelerators for studies of nuclear reactions. In the mid-1930's the world's second cyclotron was built and operated in the basement of the Sloane Physics Laboratory. (The first cyclotron was designed and built at Berkeley by the renowned E. O. Lawrence (Nobel laureate) who had been a Junior Faculty member at Yale, and had left for the West Coast after being denied tenure). Professor Howard Schultz had designed and built, almost single-handedly, one of the first four linear electron accelerators in the world. I had been aware of his pioneering work since 1952. It was a privilege for me to be a member of his group.

I immediately built and installed a new nanosecond system on the machine that generated pulses of 50-MeV electrons with peak currents of almost one ampere, and durations of 5 nanoseconds. It was a unique facility. My first graduate student arrived, and together we were able to advance the field of Photonuclear Physics at a rapid pace. After working night and day, he graduated in 3 years, setting an example for all my future students.



Before I came to Yale, Charlie Bockelman had suggested that it might be useful if I were to obtain a Ph. D. in order to “join the union”. I knew that there had been successful non-Ph. D. scientists in U. S. universities but they were few and far between. (As examples, there were Bob Pound, the distinguished Chairman of Physics at Harvard, Freeman Dyson at Princeton, Frank Anscombe and Evelyn Hutchinson at Yale). In early 1966, I contacted the Registrar of the University of London asking to be enrolled as an external candidate for a Ph. D. He replied, asking who would be my supervisor, what subjects would I study in preparation for a written examination, and what would be the subject of my thesis. I replied that I did not have a supervisor – I had started the field of very high-resolution spectroscopy in photonuclear physics, and there was no one I could turn to. I submitted a curriculum, and a title for a thesis. The governing board of the Ph.D.’s accepted my proposals, and they replied that I could submit my thesis after a period of three years. I asked for that time to be reduced to one year as I had published six papers in the field, and there was no reason for further delay. They agreed to my exceptional circumstances, and in 1967, I wrote the entire thesis in the space of four weeks, and submitted it to the authorities in London. They asked me to appear for an oral examination in London on December 21, 1967. They sent directions for my interview at Queen Mary College in Mile End. I wrote and thanked them, stating that I did not need their directions as the College was less than one mile from the Coopers’ School that I had attended as a boy. During the winter break, I went to London and had the nostalgic experience of walking from Mile End station to the College on my home territory. I went to the fifth floor of the building to Professor Ashmore’s office and looked out from his picture window to see the roof of my old school. Another examiner arrived; it was Professor Ken Allen from Oxford. We greeted each other as friends, familiar with our respective research. For an hour they asked me challenging questions concerning my thesis; we finished by discussing the difference in teaching methods in the U.K. and the U.S. They announced that I had passed with distinction, and that I had demonstrated sufficient knowledge of the entire subject that I would not have to take a written examination. Within a matter of months, I was appointed an Associate Professor of Physics at Yale, and made the Associate Director of the Electron Accelerator Laboratory. I was promoted to tenure in 1975 and to Full Professor in 1977. My random trajectory in space-time had become a straight and narrow line.

I was fortunate to have many outstanding graduate students, and they were fortunate to have a world-class research facility on campus. The electron accelerator was at the limit in size and complexity of any accelerator that could be operated in a university environment. It was, nonetheless, a do-it-yourself experience for them; they were encouraged to design and build complex equipment for experiments, and they often helped me run the graveyard shifts.

I taught several thousand undergraduates in courses that ranged from the level of “Physics for Poets” to “Physics for Physicists”. I never used textbooks in teaching;

I firmly believed that every lecture should present the material in an original way. I did, of course, recommend many books for parallel reading. In 1983, I was the first professor in the Physical Sciences to be awarded the newly introduced undergraduate teaching prize.

During my 34 years at Yale, I was Director of Graduate Studies and Chairman of the Department of Physics, Director of the Electron Accelerator Laboratory, Master of Trumbull College, and the member of numerous University committees, including the Athletics Committee (for ten years) and the Standing Committee on Undergraduate Admissions. I directed the Summer Sciences Program in the mid 1970's.

My five-year appointment at the helm of Trumbull College was made doable and enjoyable by the invaluable support of my wife Pamela, who devoted her time, energy and compassion to the students, and by the essential contribution of Pat Dallai, who constantly demonstrated her skills as an organizer, and her personal qualities as a friend and confidant to students and Fellows, alike.

I retired from Yale in 1999, having worked for fifty years with but a single break of three months in 1988 when I took one term off to go to St. Catharine's College, Cambridge as a Visiting Fellow. Since retirement, I have written three books, available on my website, [Physicsforfree.com](http://Physicsforfree.com), I have produced four papers on subjects ranging from a new proof of the Gregory–Leibniz theorem to the general use of Random Matrix Theory in Physics and Mathematics. I have built a completely new kitchen, a new deck, and I have re-pointed the chimney on my house. In a somewhat different vein, I have had three exhibits of my paintings, drawings and graphics. Ten years have gone by since my wife, Pamela, had an unsuccessful back operation. I have become a full-time caregiver. She took great care of me for 50 years, and it is my turn to take special care of her in old age. We, the first Fellows of the Koerner Center, have lived, and continue to live, in The Age of the Killing Fields. Let us hope that our students will help to bring an end to this barbaric period.