ALLADI RAMAKRISHNAN'S THEORETICAL PHYSICS SEMINAR AND THE CREATION OF MATSCIENCE*

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ABSTRACT: The story of the birth of MATSCIENCE, The Institute of Mathematical Sciences, is one of the most exciting sagas in the world of science. This article describes the efforts of Professor Alladi Ramakrishnan and the role of his Theoretical Physics Seminar in the creation of this Institute, in Madras, India, in 1962. As a background, certain important events in the scientific career of Alladi Ramakrishnan starting from 1947 are described since they served as a motivating force for this famous seminar.

1. Introduction

The story of the creation of MATSCIENCE, The Institute of Mathematical Sciences, is one of the most exciting sagas not just in Indian science, but in the world of science. A series of incredible events came together in rapid succession to bear fruit. The Institute was a direct consequence of the efforts of Professor Alladi Ramakrishnan, my father, who conducted a *Theoretical Physics Seminar* in our family home *Ekamra Nivas* in Madras during the period 1959-61. Several eminent scientists and mathematicians spoke at the seminar like Niels Bohr, Abdus Salam, Donald Glaser, Marshall Stone, and Laurent Schwartz, and some luminaries like Murray Gell-Mann and Richard Dalitz were our house guests. My mother unhesitatingly supported my father's efforts and graciously offered hospitality to the visitors and the students. Without exception, the visitors were impressed with the way in which my father was initiating modern physics in Madras with the seminar spirit that pervades the great centers of learning in America and Europe. But one in particular, Nobel Laureate Niels Bohr, who was visiting India as the guest of Prime Minister Nehru in 1960, was so impressed that he expressed his admiration for the seminar at a press conference. This attracted the attention of the Prime Minister, who at the urging of the Minister of Education Mr. C. Subramaniam, agreed to meet my father and his students on December 8, 1961 at the Raj Bhavan in Madras. At that meeting, when the Prime Minister asked my father what he wanted, my father said that he desired an Institute modeled along the lines of the Institute for Advanced Study in Princeton. Mr. Subramaniam was able to persuade Prime Minister Nehru to agree to my father's proposal to have a new institute for advanced research in the mathematical sciences be created in Madras. Thus, within a matter of weeks, MATSCIENCE was inaugurated on 3 January 1962 with my father as the Director, a position he held for 21 years until his retirement in 1983. Today, by the time of its Golden Jubilee, the Institute has established itself as one of the major research centers not just in India but in the world as well. The time is therefore appropriate to reflect on how the Institute came into existence, and what difficulties had to be overcome by my father to make his dream of a new institute a reality.

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As a young boy between 4 and 6 years of age, I witnessed the seminar activity at our home and saw the birth of this Institute. I was also very close to my father who told me his academic life story. Thus I am very familiar with the events preceding the seminar that served as its motivating force. In this article I shall describe the story of the creation of MATSCIENCE in full detail focussing on the Theoretical Physics Seminar and my father's efforts. I shall talk about the students of the seminar and the eminent visitors who lectured in it. However, to get a proper idea as to what led my father to launch this seminar, and the international visitors who lectured in it, I need to provide as a background, some important events and aspects of his career in the decade or so preceding the seminar, and it is with this we begin our description. For accuracy, I have relied on his personal diaries in which he recorded his daily activities and so I provide specific dates for certain events to give a sense of the timeline for the exciting developments. For details about certain events, I have relied on the account books of the late Mr. Nambi Iyengar, my father's personal assistant. I quote periodically from my father's autobiography *The Alladi Diary* [1] to convey his moods and thoughts as the events unfolded. (Actually I quote from the pre-publication version of the Alladi Diary which is a bit more detailed, but the reference [1] I have given is to the published version.)

Background: 1943-59

My grandfather Sir Alladi Krishnaswami Iyer was one of the greatest lawyers of India. He was a member of the Drafting Committee of the Indian Constitution. Naturally, Sir Alladi's eminence in law influenced many of his family members to take to law as well. In particular, after my father obtained a BSc honors degree in physics, he attended Law College and secured a Gold Medal in Hindu Law. When my grandfather was writing various sections of the Indian Constitution, my father assisted him by preparing drafts as per my grand father's dictation. All this was an excellent training for my father for a career in law. But that was not to be. Instead he took to a career in science.

Influenced by Bhabha: While my father was a student at the Presidency College in Madras in the BSc honors course, he heard a magnificent lecture by Homi Bhabha in 1943 on Meson Theory. My father had always a keen interest in science, and that lecture inspired him. Yet, some support was necessary from the family to eschew a lucrative profession in law and take to a career of research in science. That support came from my grandmother Lady Venkalakshmi who convinced my grand father to allow my father to pursue a career of his choice. My father was most grateful for this crucial support.

During one of his visits to Delhi with my grandfather in 1947, my father came to know that my grandfather was invited by S. S. Bhatnagar, Director of the Council of Scientific and Industrial Research (CSIR), to a dinner to meet Homi Bhabha. My grandfather could not attend that dinner, and suggested that my father could go in his place. At the dinner my father expressed to Bhabha how that lecture of 1943 on Meson Theory inspired him. Bhabha then suggested that my father should meet him in Bangalore and start working under him.

Homi Bhabha had returned to India in 1943 after doing his work in England under Dirac, and after having been elected Fellow of the Royal Society. This leading physicist who was to launch and command the Atomic Energy Commission of India, first set up

a modest Cosmic Ray Unit at the Indian Institute of Science in Bangalore. It was in Bangalore that my father first started working with Bhabha. At that time Bhabha was pursuing a problem of cosmic radiation involving electron cascades, and he introduced this fundamental problem to my father. Soon after, Bhabha moved to Bombay where with the initial support of the Tata family, he began the Tata Insitute of Fundamental Research. In the beginning, this institute was located in Bhabha's aunt's home *Kenilworth*. My father moved to Bombay to work with Bhabha at Kenilworth as one of the first members of the Tata Institute. Bhabha was a master of limit processes and so he approached this problem from that angle, using techniques from measure theory. Simultaneously, my father tackled the problem very differently using an idea he called "the method of product densities" and provided a much simpler solution. Bhabha preferred to pursue his approach, and so my father decided to leave the Tata Institute to seek recognition of his work elsewhere. He therefore returned to Madras and decided to go to England to complete his PhD.

Recognition of work and PhD in England: While working on the problem in Cascade Theory under Bhabha, my father had come across the North Carolina lectures of the well known statistician M. S. Bartlett of the University of Manchester. So my father wrote to Professor Bartlett expressing his desire to do his PhD in Manchester. Bartlett responded quickly with a positive reply. So, along with my mother, my father sailed to England in 1949. While on the ship, he obtained a substantial generalization of his method and results. Upon arrival in England, he showed this to Professor Bartlett who immediately recognized its correctness and importance. But Bartlett wanted to check with his long time associate D. G. Kendall of Oxford University whether my father's observations was anticipated in earlier work. Professor Kendall had made similar observations in the two dimensional case, but my father's technique for higher dimensions was new and important. Thus he had essentially enough work for a PhD which he received in 1951 after satisfying the two-year residence requirement. Professor Bartlett communicated my father's initial paper on product densities to the Proceedings of the Cambridge Philosophical Society. Interestingly Bhabha's paper appeared in the same month in the Proceedings of the Royal Society. Thus it was a positive ending for my father with regard to the timely publication of his important work in a major journal. His prospects looked very bleak when he left the Tata Institute and it was the support and swift action of Bartlett and Kendall that saved him.

Even though my father left the Tata Institute due to lack of recognition of his work, he never expressed anger against Bhabha by criticising him in public or in writing. On the contrary, he was grateful that Bhabha gave him a good problem to work on and acknowledged this on many occasions, but he was disappointed the Bhabha did not recognise his ideas. He admired Bhabha for his brilliance and charisma and even after leaving the Tata Institute, he tried to maintain good relations with his teacher as will be seen from some of the events that took place after his return to India from England. Before describing what else happened to my father during his stay in England, it would be appropriate to quote my father on his feelings regarding this episode with Bhabha from a keynote address he delivered at the inauguration of a conference on stochastic processes in Madras in 1998 [3]: "Bhabha summoned me as his research student and gave me the greatest gift a *Guru* can give a *Sishya*: the unsolved problem of cosmic radiation. The architect of Cascade Theory

reslised that cascade multiplication in cosmic ray showers was a random or stochastic process which involved the distribution of a discrete number of particles in continuous energy space. The gap between enumerable infinity and continuous infinity is unbridgeable, yet it is a fact that particles are distributed at random in a continuous infinity of energy states. Bhabha was a master of the limiting process and so he divided the energy interval into large number of small intervals and applied the concept of density of states familiar to physicists. To understand the magnitude of the problem, he arranged lectures on measure theory by F. W. Levi and asked me to master the book of Uspensky and the classic article of Kolmogorov on probability theory. This led me to a direct formulation based on the perfectly sound assumption that in an infinitesimal dE, the probability of there being n particles is of the order $(dE)^n$ and so the contribution to the density comes from the occurrence of a single partyicle in dE. This was the mathematical equivalent to the prolonged limiting process of Bhabha.

At that time Bhabha was under the influence of Dr. D. D. Kosambi who could not appreciate the simplicity of my formulation. In England Professors Bartlett and Kendall were concerned with a similar problem in the age distribution in population growth, and when I sent them the summary of my work, they were immediately impressed with its correctness and simplicity. So I joined Bartlett's team at Manchester in 1949 and while Bhabha published his papers in the Proceedings of the Royal Society, my paper was communicated by Bartlett and published in the Proceedings of the Cambridge Philosophical Society based on the elegant notation suggested by D. G. Kendall."

While doing his PhD in Manchester, my father attended several conferences and visited other universities in the United Kingdom. Of note was the Conference on Modern Physics in Edinburgh, Scotland, in the winter of 1949, where he met Nobel Laureates Niels Bohr, Werner Heisenberg, and Max Born. At this conference there was a lecture by Professor Janossy from Dublin, who presented his approach to the fluctuation problem of cosmic radiation. In the discussion following that lecture, my father outlined his approach to that problem via the method of product densities. This resulted in an invitation to Dublin, as well as to Scandinavia where my father visited the Bohr Institute in Copenhagen, Denmark, The Cramer Institute in Stockholm, The University of Stockholm, The University of Uppsala, and The University of Oslo. Many of these contacts made during his stay in England were crucial in his career, and some of these scientists visited him in Madras and lectured at his Theoretical Physics Seminar as we will see in the sequel.

Appointment and research at Madras University: After obtaining his PhD at the University of Manchester in 1951, my father returned to India. Enroute, he and my mother spent a few weeks in Switzerland. During this interlude, while in Geneva, my father met Sir A. L. Mudaliar, the Vice-Chancellor of Madras University. Sir Mudaliar informed him that the the University was starting a Department of Physics, and that my father could apply for a position there. When my father applied, he was offered the position as Reader (= Associate Professor) in Physics at the University of Madras in 1952. The position of Professor of Physics was occupied by G. N. Ramachandran, who was leading a programme on crystallography in the Department. Upon joining the University, my father began a series of lectures on Methods of Mathematical Physics based on the notes of M. J. Lighthill who lectured on this topic at Manchester during 1949-51. Two MSc students who

attended my father's lectures were P. M. Mathews and S. K. Srinivasan and they became the first two of his PhD students.

For nearly a decade after his return from England, my father by himself and with his students, continued to work at the University of Madras on extensions of the theory of product densities and its applications to cascade theory in physics, fluctuation problems in astrophysics, and to biosciences. His interest in problems in astrophysics came by studying certain papers of the great astrophysicist Subrahmanyam Chandrasekhar (University of Chicago), and by noting that certain aspects of Chandrasekhar's work could be simplified and extended. Along with his first PhD student P. M. Mathews, he published a few papers in the Astrophysical Journal on a certain integral equation of Chandrasekhar and Munsch. All in all, during the period 1952-57, my father published seven papers in the Astrophysical Journal (by himself and with his students Mathews, Srinivasan, and Vasudevan) all communicated by Chandrasekhar who was the Editor.

My father's advisor M. S. Bartlett had studied various applications of probability and statistics in biosciences, especially relating to population growth, and so my father also turned his attention to such questions. In this connection, he worked with his second student S. K. Srinivasan, who subsequently joined the mathematics department at the IIT Madras after his PhD. There Srinivasan pursued various ramifications of the theory of product densities by himself and with his students and eventually rose to the position as Head of the Mathematics Department.

Over the next few years, many more students in the MSc Physics course at the University of Madras approached my father with the intention of doing their PhD under his guidance, and he willingly accepted them. Thus his influence on the development of theoretical physics in Madras was growing steadily. On the basis of his work by himself and with his students, he was offered a contract in March 1954 by Pergamon Press of England to write a book on Cascade Theory. The contract came owing to the recommendation of Professor Heitler, who along with Bhabha was one of the architects of Cascade Theory. My father accepted the contract, but the book took six years to be completed by which time it expanded to be a treatise on Elementary Particles and Cosmic Rays.

Visit to Australia: In 1953 my father received an invitation from Harry Messel to spend a few months as a visiting scientist at the University of Sydney in the rapidly growing physics department there. My father had met Messel in 1949 during a visit to Dublin under the invitation of Janossy and the invitation to visit Sydney was a direct consequence of that early contact with Messel.

The visit to Sydney was actually in 1954 and my mother accompanied him. In Sydney, my father gave a series of lectures on stochastic prcesses, the notes of which became the basis of his famous article on this topic in the Handbuch der Physik a few years later. During the course of these lectures, he arrived at some novel interpretations of integrals of random functions, which resulted in two papers of his in the Proceedings of the Netherlands Academy of Sciences in 1955.

While in Australia, my father visited The Australian National University in Canberra, and lectured in the Statistics Department at the invitation of Pap Moran, an associate of Professor Bartlett. He also spent some time with the famous physicist Sir Mark Oliphant, a former associate of Lord Rutherford. When Oliphant said that he was planning to

visit India under the auspices of the Royal Society, my father invited him to deliver the Rutherford Memorial Lecture at the University of Madras.

Elected Fellow of the Indian Academy of Sciences: Almost from the start of his tenure at the University of Madras, my father actively participated in several conferences throughout India and took his students with him to make presentations. In particular, he actively participated in the meetings of the Indian Academy of Sciences conducted by Sir C. V. Raman, its illustrious founder. In one of the meetings of the Academy, my father presented a talk on his new work on *Inverse Probability*. Sir Raman was much impressed by my father's talk and his earlier work, and so in 1954 said that he would have my father proposed by G. N. Ramachandran for election as Fellow of the Indian Academy of Sciences. Within a few weeks my father received a letter from Sir Raman informing him of his election as Fellow.

The first three distinguished visitors: In order to inspire his students, and to strengthen his own research programme, my father was keen to get eminent physicists from overseas to visit the University of Madras and engage in discussions with them. During 1954-55, three world famous physicists who were visiting India, came to Madras for lectures and spent time at his family home for leisurely and prolonged discussions on modern physics. They were Nobel Laureates P. A. M. Dirac and C. F. Powell, and Sir Mark Oliphant.

In December 1954, Professor Dirac and his wife (who was the sister of Nobel Laureate Eugene P. Wigner) visited Madras. Professor Dirac, one of the greatest physicists of the twentieth century, graciously accepted my father's invitation to give a lecture at the Senate Hall of the University of Madras. My father sent around a circular stating that "Dirac is the architect of the only valid relativistic wave equation of an elementary particle - the electron, imbedding with unqualified success, relativity into quantum mechanics." The Senate Hall overflowed with many eager listeners hearing the lecture on loud speakers while in their cars on the parking lot! There was a dinner in honour of the Diracs at Ekamra Nivas and my father invited several representatives on the Madras elite to meet the legendary physicist. During their stay in Madras, my father took the Diracs on a trip to Mahabalipuram and to Thirukazhikundram to see the eagles that came at specific times for feeding by the priests. Dirac was the first international physicist to visit Ekamra Nivas and one could not have had a better start for the stream of visitors to my father's family home.

A natural consequence of my father's visit to Australia was Sir Mark Oliphant's acceptance to deliver the Rutherford Memorial Lecture at the University of Madras in early 1955. Professor Oliphant stayed at Ekamra Nivas, and being a vegetarian himself, enjoyed the superb South Indian vegetarian food offered at our home. Many years later, in 1973, when my father visited Australia, Oliphant was the Governor of South Australia, and he had my father as his personal guest in the Governor's Mansion in Adelaide, thereby repaying graciously the hospitality my parents offered him in Ekamra Nivas.

In December 1955, Nobel Laureate C. F. Powell visited and lectured at the University of Madras. My grandmother Lady Venkalakshmi was very ill at that time, and so instead of having Professor Powell at home, my father hosted a dinner for him at the roof garden of the Dasaprakash Hotel, which later became a regular second venue for dinners for many

distinguished visitors.

The visits of Dirac, Oliphant, and Powell, was the informal beginning of the Theoretical Physics Seminar, although the seminar formally began only in 1959.

First Round-the-World Tour of 1956: This first of many academic trips around the world for my father, was perhaps the most significant and influential in his carreer.

The trip began in February 1956 with a six week stay at the famous Yukawa Hall in Kyoto, which was the Institute headed by Nobel Laureate Hideki Yukawa. The atmosphere of Yukawa Hall with its steady stream of eminent visiting scientists and the inspiration they provided to the many young Japanese scientists, greatly influenced my father. During the speech my father gave for the inauguration of MATSCIENCE, he said: "In the 'domestic' environment of the Yukawa Hall, young Japanese physicists, the hope and pride of their country, just resurrected from the second World War, gathered together in enlightened leisure to discuss the most abstruse problems of modern physics. That strange enchantment drew me into the domain of elementary particle physics and I played with the idea of creating something like the Yukawa Hall in my own home town where my great father made his legendary reputation in another field of intellectual activity." My father says in his Diary: "I had many exalting experiences during my stay at Yukawa Hall. Professor Powell who had won the 1950 Nobel Prize for his work on Cosmic Radiation, visited Kyoto at the time and gave a magnificent lecture on new particles. In his honour was arranged a seminar by young Japanese physicists in which Sakata announced his now famous model. Of course we did not realise at that time that it was going to be the primitive source of Gell Mann's formulation of unitary symmetry which dominates physical thought today." Later in his Diary, my father says: "My seminar on 'Probabilistic aspects of three dimensional cascades' was well attended and it was a thrilling moment when Professor Yukawa entered the hall and sat in front to listen to my talk along with Professors Hayakawa and Nishimura". My father's stay at Yukawa Hall was supported by the Asia Foundation.

At Yukawa Hall my father made contact with several young Japanese physicists, including Dr. Ueno who was interested in astrophysical problems, Dr. Fujiwara who investigated quatization, Dr. Fukuda who was studying many body problems, and Ziro Koba who worked on quantum mechanics. Later Koba was one of the first visitors to the Theoretical Physics Seminar during its formal launch in 1959. Fukuda visited MATSCIENCE in 1963 and lectured in the Summer School that year.

During his stay in Kyoto, my father visited the neighbouring city of Osaka where he met Dr. Oda at Osaka University. Oda had trained under Bruno Rossi of MIT whom my father met later in the trip while in the United States.

After his visit to Kyoto, my father proceeded eastward and visited Dick Bellman at the RAND Corporation in California. Correspondence between Bellman and my father had originated in 1949 when my father noticed connections between his work on product densities and the fundamental paper of Bellman and Harris in the Proceedings of the National Academy of Sciences, USA. Thus it was productive to visit Bellman and discuss further ramifications. Although Bellman could never visit Madras in response to my father's invitations, the visit to RAND in 1956 began a long and fruitful academic relationship between my father and Richard Bellman. This not only resulted in many visits of my father to California at Bellman's invitation, but also led to extended visits by my

father's student R. Vasudevan who collaborated with Bellman on several projects.

In addition to interacting with Bellman, my father made several important contacts in and around Los Angeles during that visit. He met Ted Harris, Bellman's famous collaborator at RAND. But perhaps the most memorable event of the visit to California, was the meeting with Richard Feynman at Caltech on 28 March, 1956, that Bellman arranged at my father's request. My father says in his Diary: "The most interesting day of my entire academic career was when I met Feynman at Caltech. ...Feynman is an amazing personality and I took courage to talk to him about his vision of quantum electrodynamics. He spent over three hours with me and gave a really first hand account of his interpretation of a positron as an electron travelling back in time.... However, while I admired Feynman's genius, at the end of the discussion I was excited about the possibility of reinterpreting his concept of the electron *travelling back in time* as really *tracing back in time* in the light of my own familiarity with stochastic processes and inverse probability." This possibility became a reality, because a few years later, my father was able to get a simple proof of the equivalence of the Feynman and the field theoretic formulation by splitting the Feynman propagator into positive and negative energy parts. The first person to have established this equivalence rigorously was Dyson, but only a few have really understood Dyson's deep and difficult derivation.

That same afternoon, following the meeting with Feynman, Bellman took my father to the Mt. Wilson Observatory for him to meet Guido Munsch, a student and collaborator of the Subrahmanyam Chandrasekhar. My father and his student Mathews had worked on and simplified certain aspects of the treatment of Chandrasekhar-Munsch on an integral equation, and so my father was keen to make acquaitance with Munsch. There at Mt. Wilson, my father also had the opportunity to meet Otto Struve, one of the greats in the field of observational astronomy. Thus the visit to California was extremely fruitful.

From California, my father flew to Rochester to participate in the High Energy Physics Conference (April 3-7) at the invitation of its organizer Professor Robert Marshak, a famous physicist. The lectures at the conference and the contacts he made there had a profound influence on his career and on the creation of MATSCIENCE. It is best to describe his experience at the Rochester conference by quoting him from his Diary: "I went to the University of Rochester to attend the High Energy Physics Conference for four days. The entire panorama of high energy physics was unfolded in a flash. The conference had a terrific impact on me who until then was a complacent votary of British institutions. I found that the centre of gravity of creative science had shifted from Europe to the United States. The affluence and the academic freedom of the American university campuses were attracting even the most nationalistic scientists from Europe for permanent residence in the USA. Besides these, a new brand of American scientists had gained leadership in the mathematical sciences. Gell Mann, Goldberger, Feynman, Chew were all there at the conference organised by Marshak the architect of the Rochester conferences which was held later in rotation at various centres of the world."

It was at this conference that my father had a most incredible meeting with Robert Oppenheimer, Director of the Institute for Advanced Study in Princeton. I quote from my father's Diary:"It was during lunch time that a fortuitous incident occurred which altered the course of my scientific career. Since I was a stranger to the group of high energy

physicists, I sat alone at a separate table in the cafeteria when Oppenheimer walked in, and with a politeness characteristic of true greatness, asked me whether he could join me for lunch at the table. When he asked me what my future plans were, I took the opportunity to express to him my desire to spend a year at the Institute for Advanced Study. Though I was a seasoned probabilist, I was only a novice in relativistic quantum mechanics. I wanted to learn from the high powered seminars (at Princeton) rather than go through the grinding mill of graduate courses. My ambition was to be realised a year later when I received from him a gracious invitation."

From Rochester my father went to Boston for two weeks (April 9-26) where he gave four lectures on stochastic processes at MIT in the Norbert Wiener Seminar at the invitation of Professor Bayard Rankin. Following the seminar, the famous Italian born physicist Bruno Rossi hosted a dinner in my father's honor. After Boston, he was off to Chicago for a week (27 April - 6 May) to meet the great astrophysicist Chandrasekhar, or "Chandra" as he was affectionately called by his friends. Although my father had corresponded with Chandrasekhar and had published papers in the Astrophysical Journal, it was his first meeting with Chandrasekhar who was Morton D. Hull Distinguished Service Professor at the University of Chicago. There at the University my father heard Chandrasekhar's lecture on radiation theory and was struck by his thoroughness in preparing even regular seminar lectures. Chandra took my father to Yerkes Observatory where he worked with a team of observational astronomers to confirm his scientific theories. My father had discussions with Chandrasekhar and his associates Gerard Kuipers and Prendergast on the topic of turbulence. At the University of Chicago, my father gave a seminar on statistical problems in astronomy. In the audience was Professor Bengt Stromgren with whom my father was to renew his acquaintance a year later at the Institute for Advanced Study.

After Chicago, my father went to Washington D.C. on 8 May to visit Peter Chiarulli at the National Bureau of Standards and Maurice Shapiro at the Naval Research Laboratory. Shapiro and my father began a long friendship. Shapiro visited Madras thrice, the first time in 1960, and two times later after MATSCIENCE was created. His visit in 1960 to the Theoretical Physics Seminar was crucial in the creation of MATSCIENCE as we shall see in the sequel.

My father departed for Europe, and after meeting his PhD advisor Bartlett at the University of Manchester and giving a seminar there, he proceeded to Zurich on 20 May where he had several meetings with Professor Heitler. During these meetings, he discussed the proposed contents of his book on Cascade Theory that Professor Heitler has contracted him to write. In the next five years the students of the Theoretical Physics Seminar worked closely with my father in writing chapters for this book because it related to their research program.

The next stop in Europe was Stuttgart where my father attended the GAMM Conference. There he presented a paper on "Ergodic properties of some simple stochastic processes" in which he introduced new concepts like the probability distribution of the time spent in a particular physical state. My father continued his stay in Germany with visits to Heidelberg as the guest of Professor Hans Maass, and then to Gottingen where he spoke on the stochastic problem of cosmic radiation at the Heisenberg Seminar. Nobel Laureate Werner Heisenberg made very favourable remarks about my father's work during

the seminar and how it compares well with experimental data he was looking into. In that connection my father had discussions with Mr. Fay of Heisenberg's group who explained to him the experimental work being done in Gottingen on electromagnetic cascades. My father writes in his diary:"I lay in bed thinking of the cascade problem described by Fay. A new approach to Cascade theory suggested itself to me and this implied that I could give my student Srinivasan enough work to complete his PhD thesis".

Professor Flugge of the University of Marburg who attended my father's lecture in Gottingen, was much impressed by Heisenberg's comments about my father's work, and so he invited my father to Marburg. There Professor Flugge offered a contract to my father to write an article on stochastic processes for the Handbuch der Physik published by Springer-Verlag.

Thus the First Round-the-World academic Tour of 1956 had a profound effect on my father's career and research, as well as on his PhD students.

Work in India, 1956-57: Immediately upon return from his world tour, my father began writing the article on stochastic processes for the Handbuch der Physik with the assistance of his PhD students S. K. Srinivasan and R. Vasudevan. That was a very good training for them since they were going to get their degree in the field of stochastic processes.

Since my father was exposed to exciting advances in particle physics at the Rochester conference, he supplemented his lectures on stochastic processes at the University of Madras and elsewhere in India, by talks on quantum electrodynamics and relativistic quantum mechanics. This had the effect of attracting more students to work under him - but in theoretical physics and not just in stochastic processes. Two students who joined the MSc Course of my father in 1956-57 were V. Devanathan and G. Ramachandran. At the invitation of Sir C. V. Raman, my father gave a talk at the December 1956 meeting of the Indian Academy of Sciences on "A physical approach to stochastic processes".

In January 1957, Harry Messel from Sydney visited Madras and had discussions with my father and his students. This resulted in an invitation from Messel to S. K. Srinivasan to visit Sydney towards the end of the year.

Visit to the Institute for Advanced Study, Princeton, 1957-58: In February 1957, my father received a letter from Robert Oppenheimer, inviting him to visit the Institute for Advanced Study for the academic year 1957-58. My father applied to the Asia Foundation for the travel grant to go to Princeton, and this was promptly awarded. The Institute provided a grant-in-aid to defray my father's living expenses for the year.

My father left for the United States on 20 September, 1957 along with my mother. Since I was just two years old, and the Princeton winters were considered too harsh for an infant, I was left behind in Hyderabad to be taken care of my father's older brother and his family.

Enroute to Princeton, my father decided to attend the High Energy Physics Conference that took place in Venice and Padua. Nobel Laureate Heisenberg gave the introductory lecture of the conference. In addition, my father heard lectures by Nobel Laureates Wolfgang Pauli and C. F. Powell, the latter giving a summary of experimental data in physics analogous to the talk that my father heard Pauli give a year earlier in Kyoto.

From Italy my parents stopped briefly in Germany where my father had a meeting

with Professor Flugge to report on the progress being made on the article for the Handbuch der Physik. From Germany my parents flew to the USA to spend a year at the Institute for Advanced Study starting in early October 1957.

Fuld Hall was the imposing main building of the Institute. My father's office was in an adjacent building - an office that he shared with Mike Cohen who had just received his PhD under the direction of Richard Feynman. This close contact with Cohen proved useful, because a few years later, my father was able to recommend his MSc student Deshpande for a PhD fellowship under him, when Deshpande was a member of the Theoretical Physics Seminar.

The academic year 1957-58 that my father spent at Princeton was a turning point in his career. He heard over one hundred seminars at the Institute by the leaders of modern physics on the latest and most important developments - Rick Jost and Sam Treiman on the CPT Theorem, Bengt Stromgren on astrophysics, Rudolf Haag on scattering, Marvin Golberger on dispersion theory, and Abraham Pais and Sam Treiman on weak interactions. T. D. Lee and C. N. Yang were in residence at the Institute and everyone was excited about their recent sensational discovery of non-conservation of parity and wondered whether they would win the Nobel Prize, which they did that year.

Einstein, the most celebrated of the members of the Institute, had died in 1955, and so my father did not get an opportunity to meet him. Instead he got to meet Robert Oppenheimer whose presence dominated most of the seminars. In his Diary, my father describes his contact with Oppenheimer at the Institute: "My first meeting with Oppenheimer fulfilled my expectations about this legendary figure who dominated not only American science, but influenced the destiny of the world as the architect of the atom bomb. Lean and of medium height, he had an oval head, prominent cheek bones and piercing eyes. He could pick his men while lighting his pipe, each for the appointed task according to his talent and inclination, from a Nobel prizeman to a truck driver. He was magnanimous in providing opportunities for young scientists, and enjoyed discussions at every seminar where his very presence invited impartial criticism.....

His intellectual interests ranged from theoretical physics to Hindu philosophy, and in Rabi's estimate he understood the whole structure of physics with absolute clarity....It was said that he had two passions - physics and the desert! He found the one in the other when at the age of forty he was called upon to undertake at Los Alamos a task unprecedented in its objective, undefined in its scope, unpredictable in its consequences - the creation of the atom bomb. It was a leap into the unchartered future of mankind and he achieved it with the pragmatism of an American and the vision of a universalist. Tormented by moral ambiguities, he found his haven at the Institute for Advanced Study, the environment to which he belonged - from the innermost recesses of Gell Mann's quarks to the outermost bounds of Einstein's universe. It was going to be a transition period in my scientific career for I was moving into Elementary Particle Physics after having completed my article on stochastic processes for the Handbuch der Physik. Princeton was the centre of things and I could not ask for a better place being a late entrant to theoretical physics.

For me the first revelation was the distinction between multiplicative and additive quantum numbers. ....The second revelation was the structure of the algebra of Dirac matrices. While in the Dirac equation there occurred only four anti-commuting matrices,

the was a fifth one - the gamma five - which was ignored hitherto, but had to be invoked to explain weak interactions. I remember how with friendly interest, Oppenheimer gave me the preprint of Feynman and Gell Mann asking me to understand the role of the gamma-five! It took me ten years to understand this mystery and I could resolve it totally when in 1967 I obtained a hierarchy of matrices of the Clifford algebra and their generalizations."

Although my father's interests were shifting to elementary particle physics, he continued to work on probabilty and stochastic processes while in Princeton. In particular, he completed a paper on multiple product densities with his PhD student S. K. Srinivasan who was visting Harry Messel in Sydney at my father's recommendation.

During his stay at Princeton, my father attended the Annual Meeting of the American Physical Society in New York. His first PhD student P. M. Mathews, who was visiting Ottawa, came to this meeting. There my father introduced Mathews to Prof. Falkoff and this resulted in Mathews getting a post-doctoral fellowhip at Brandeis University the following year. Another visit while at Princeton was to Case Western University in Clevland at the invitation of Professsor Bayard Rankin. After this my father visited the University of Chicago at the invitation of Subrahmanyam Chandrasekhar. Thus the one year in Princeton exposed my father to the revolutionary developments in elementary particle physics, and the opportunity to hear about these developments in seminars delivered by the makers of modern physics. In addition, my father had also the opportunity to visit other centres of learning and make further new contacts that helped his own research programme and the career of his students.

In April 1958 my parents departed Princeton for Madras. After having been infected with the seminar spirit at the Intitute for Advanced Study, my father returned to India full of visions to create in Madras a centre for advanced learning that would have the spirit of Princeton. This dream that began in Fall 1958 became a reality four years later through the Theoretical Physics Seminar that my father conducted at Ekamra Nivas, and I describe this next.

The Theoretical Physics Seminar, 1958-59

The seminar begins: The message of Princeton that my father wanted to convey to his hometown of Madras was that "the seminar was the essence of intellectual activity, where there is as much desire to imbibe as there is to impart, where opportunities are provided for a clash of intellects which would produce creative ideas." Since the atmosphere at the University was sterile, he started a vigorous series of seminars at Ekamra Nivas on various aspects on modern physics, and invited his MSc students to attend them to broaden their horizon and expose them to the exciting world of research. My mother who had accompanied my father to Princeton and other great centers, understood the significance of this effort by my father and generously agreed to "open the doors" of our family home to the students and visitors. P. M. Mathews and S.K. Srinivasan had already finished their PhD, but attended the seminars to continue their research. Two new PhD students R. Vasudevan and N. R. Ranganathan were making good progress on stochastic problems in physics and astronomy. V. Devanathan who had joined the A. C College of Technology in 1957 as a Lecturer in Physics after a one year MSc Course under my father, now registered in 1958 to do a PhD under him. Devanathan had mastered angular momentum

techniques inspired by Leonard Schiff's classic book. My father gave him Edmond's book on angular momentum that he had brought from Princeton and asked him to study it and give seminars. Indeed Devanathan continued to work on angular momentum for most of his career and even guided his own PhD students in that area several years later.

G. Ramachandran who initially joined the Seminar in 1957 along with Devanathan while in the MSc, also registered under my father for a PhD. He also worked on the quantum theory of angular momentum. After receiving his PhD in 1963, he helped my father at MATSCIENCE in the guidance of two students K. Ananthanarayanan and R. K. Umerjee. Subsequently at the University of Mysore, G. Ramachandran guided several PhD students, inspired by what he had seen at the Theoretical Physics Seminar.

In June 1958, a few of the new students in the MSc course started attending my father's seminars at home. One of them was A. P. Balachandran, who after completing his PhD under my father's guidance, went to the United States a few years later to further his academic career. Besides the MSc students, there were two other regular attendees of the seminar - V. K. Viswanathan and V. Radhakrishnan, both of whom gave up their lecturer positions to attend the seminar and pursue research. But after completing their Masters, both Viswanathan and Radhakrishnan went to the United States for their doctoral work, and my father graciously helped them get doctoral fellowships in Rochester and Canada. Radhakrishnan joined MATSCIENCE in the 1970s as a faculty member and stayed there until his retirement. Viswanathan was for many years at the famous Los Alamos Research Lab in the United States until his retirement. Another MSC student to join the Seminar in 1958 was P. Rajagopal. After completing his MSc, Rajagopal left for Cambridge University in 1960 to do a PhD in Chemistry.

By July 1958, my father was regularly giving seminars at our home on Lee and Yang's paper on weak interactions, on Geoffrey Chew's work on strong interactions, as well lectures on Feymnan kernels, and the Dirac algebra. All this was in addition to his lectures for the MSc course at Madras University where he was Reader in physics. Many new students attended these seminars at our home, but the University took no cognisance of my father's efforts. At that time, Madras University, led by the authoritarian Vice-Chancellor Sir. A. Lakshmanaswamy Mudaliar, decided to open an extension centre in Madurai, and asked my father to shift to Madurai to start the physics department there. Several decades later, this extension centre became the Madurai University.

My father was very much upset at being asked to shift to Madurai, but agreed to do so. I quote from his Diary about his reactions to this assignment in Madurai: "What really pained me was that the University took no cognisance of the valuable experience I gained at Princeton, where I had heard over one hundred and fifty seminars by world famous physicists, and I wanted to initiate work in high energy physics in a university which had among its alumni Raman, Ramanujan, and Chandrasekhar. The only reward for my enthusiasm was the modest compliment of banishing me as a professor to an extension centre. I found no alternative but to accept the professorship, since otherwise someone else would be appointed and would later wangle a transfer to Madras above my head." My father was Reader in Madras and was being transferred to Madurai in the rank of a Professor.

Handling Madurai assignment and student supervision in Madras: Since I was only three years old, my father decided not to take me and my mother to Madurai, and went there by himself. That meant that he would be visiting Madras frequently to be with his family, and also to supervise his students who were in the MSc class. My father says in his Diary: "The University extension Centre in Madurai was a mere name. It had neither buildings nor a library. It had neither body nor soul. The ill furnished and crowded rooms at the colleges where I was asked to teach had a depressing effect since I had just returned after spending a year at the Institute for Advanced Study..."

An interesting opportunity arose unexpectedly. My father was invited to serve on a National Committee for Hindi terms in the physical sciences. Even though he knew no Hindi, he accepted the assignment because he could stop in Madras enroute to Delhi for frequent committee assignments. He says in his Diary why he accepted the assignment: "I knew that money was available in India for such committees even though funds were denied for symposia and lectures! This would give me greater freedom of movement and the possibility of contact with higher authorities in Delhi whose attention I could draw to my vision and efforts in Madras." Also of interest was that the Madras University allowed my father conduct the MSc course in theoretical physics during specific periods of the academic year 1958-59. He lectured to the students (the first batch for MSc in theoretical physics) Feynman graphs, strange particles, and invariance principles.

It was while in Madurai that my father wrote to Sir C. V. Raman offering to organise a session on stochastic processes at the Indian Academy of Sciences Meeting in Baroda in December 1958. Sir Raman graciously agreed to this request, but suggested that the lectures should be of wide appeal and emphasize the relationship between theory and experiment. My father was able to take several of his research students to the Baroda meeting and have them give lectures on their work. It was a great experience for them to speak in the dominating presence of Sir Raman in the front row!

The formal creation of the Seminar: In late January 1959, Professor Janossy, whom my father had made contact with in Great Britain 1949, arrived in Madras from Budapest. He was a Hungarian and had since then moved to Budapest as the Director of the Eotvos Lorand Institute. He was engaged in the probabilistic interpretation of quantum mechanics and had made contributions of great originality to this difficult domain. My father's students had been exposed to Janossy's work, and to hear him directly and have discussions with him was extremely fruitful for them. At that time my father was holding his regular MSc Physics classes in a room in the Senate House of the University of Madras, and conducting informal but advanced seminars at his home. Since these seminars were a regular feature supplementing the MSc course, he decided to formalize it in March 1959 and called it the *Theoretical Physics Seminar*. V. Devanathan, one of most dedicated and pleasant mannered of his MSc students, was made the Secretary of the Seminar. It was decided to take advantage of eminent scientists visiting or travelling through India and invite to speak in the seminar quite frequently.

Almost as soon as the Seminar was launched, my father received a letter in April 1959 from Prof. K. A. Brueckner at the University of California, San Diego (UCSD), offering a post-doctoral fellowship to any student my father would recommend. Thus Brueckner had a very high regard for my father's work and efforts to train students. My father

recommended R. Vasudevan who was just finishing his PhD under my father's guidance. Thus Vasudevan left for UCSD in August 1959 to work with Brueckner for four years. He did very well in that post-doctoral assignment, and returned only after MATSCIENCE was created, but in the position as Permanent Member. Vasudevan did so well that Brueckner once again offered a similar post-doctoral position two years later to any student of my father's choosing. Brueckner who had done important work on many body problems and condensed matter physics, had just joined UCSD and was recruited there to start a physics department. He also had a major collaboration with Murray Gell-Mann on random phase approximations and Feynman diagrams. At UCSD he was given post-doctoral fellowships in the effort to build the physics department there.

In addition to exposing his students to lectures by foreign visitors at the Seminar, my father also took his students regularly to participate and lecture in conferences and summer schools being held in various parts of India. During May-June 1959, there was a Summer School on Theoretical Physics organized by the Ministry of Scientific Research in Mussoorie. My father took his students R. Vasudevan, V. Devanathan, K. Venkatesan, and G. Ramachandran to this summer school. My father says in his Diary "The moving spirit of the summer school was Satyen Bose, the doyen of theoretical physics in India, and very sympathetic to the aspirations of the young scientific community. He was more interested in stimulating creative thought than in expository talks at the conference... In my speech I exhorted that the Mussoorie spirit should pervade Indian science in due course." At the summer school my father presented a new approach to perturbation theory discussing the meaning of the kernel function forward and backward in time, and deducing the Feynman formalism from a new point of view. Professor Bose was much impressed by this new approach. My father published three papers in the proceedings of the Mussoorie conference including one on the above topic.

In June 1959, my father returned to Madurai to continue his teaching of the MSc course there. He took with him his students N. R. Ranganathan, A. P. Balachandran, and V. Deshpande, who had just joined the course. It was at this time in August that my father received an invitation from the University Grants Commission to serve on an Expert Committee to recommend proposals for the advancement of mathematical sciences in India. It was indeed ironic to be appointed on this Committee when my father's efforts to initiate advanced physics in Madras was ignored by the University! My father accepted the assignment since it would give him an opportunity to get acquainted with the mathematical scene in India.

The first visitors after the formal launch of the Theoretical Physics Seminar were Professors Ziro Koba whom my father met during his visit to Yukawa Hall in 1956, and Dr. Kotani who hosted my father in Tokyo also during the 1956 academic trip. Professor and Mrs. Kotani stayed at Ekamra Nivas and therefore had leisurely discussions with my father and his students. There was a dinner at Ekamra Nivas in honor of the Japanese visitors on September 1. Soon after, Professor Andre Mercier from the University of Berne lectured in the Seminar. He was one who had close association with many of the grand masters of European science. Mercier formed such a favourable impression, that he invited my father to Berne on a major assignment a few months later.

Meeting C. Subramaniam - his visit to the Ekamra Nivas: One of the turning points was the unexpected meeting of my father with Mr. C. Subramaniam in October 1959 and his visit to the Ekamra Nivas shortly thereafter to meet the students of the Seminar. I describe this meeting as recalled by my father in his Diary: "During the Dasara season of 1959, I received an invitation to an international gathering of African and Asian students at the Woodlands Hotel with C. Subramaniam as their Chief Guest. He was then the Minister for Education and Finance at the same time in the Madras Government. I knew of him and had met him in New Delhi during the momentous days of the Constituent Assembly when he was a blackhaired young congressman who came to have discussions with my father. But I did not know him personally. I did not feel enthusiastic about going to the meeting since I felt that he may not have a real interest in higher education or creative science. So that evening I decided to go and relax in the Marina beach with my wife Lalitha. As the car was about to take a turn towards the beach, she suggested that we should respond to the invitation and attend the meeting for at least half an hour, to which I consented most unwillingly.

At the meeting, one of the topics that came up for discussion was about racial prejudice and how these students should tackle this in India... When I was was asked to give my views, I stressed that racial prejudice or prejudice in any form is best tackled by demonstration of good performance. Such snobbery exists even in the realm of science and in many professions. When my father started his legal profession (in Madras), he was warned that it would be difficult to succeed unless one has tasted the waters of the Cauvery. But within seven years, with hard work and dedication, he became the unrivalled leader of the Madras Bar and had several juniors who hailed from the banks of that famous river! Similarly in modern physics when it was generally agreed that Europe was the seat of science and culture, with the efforts of Oppenheimer and the new generation of scientists, the centre of gravity shifted to the United States. This speech of mine impressed Subramaniam so much that he asked me to meet him at his official residence *The Cooum House* near the Marina beach. I wasted no time and emphasised to him the need for providing suitable opportunities to the band of theoretical physicists working with me. I invited him to dinner at my house to which he readily responded. It was at that dinner he suddenly asked me to explain what I meant by *suitable opportunities* for creative science. I told him plainly that it was something like the Institute for Advanced Study in Princeton." Mr. Subramaniam was much impressed with the Theoretical Physics Seminar and took note of my father's suggestion to launch a new institute. During the years 1960 and 61, several world famous scientists spoke at the Theoretical Physics Seminar and Mr. Subramanian came to our home on many occasions to meet the visiting scientists and have discussions with them over dinner.

A steady stream of visitors: It was also in October 1959 that Professor Dallaporta from the University of Padova, Italy, visited the Seminar. This was followed by the visit of the nuclear physicist A. M. Lane from Harwell, England in December. He and his wife stayed at Ekamra Nivas. He appreciated the work of my father and his students in nuclear physics and their emphasis on numerical calculations and comparison with experimental data. Since Devanathan had chosen nuclear physics as the subject of his research, he was in charge of arrangements for the Lanes in and around Madras including the excursion to

Mahabalipuram.

Another visitor in December was George Gamow from the University of Colorado at Boulder. Gamow was a brilliant nuclear physicist who had influenced American scientific life not only by his own famous contributions but also through his interpretation of relativity and quantum mechanics to the world at large. My father says in his Diary about Gamow: "His scintillating wit, his exuberance and friendliness, sent a wave of ecstacy through our group."

The Theoretical Physics Seminar 1960-61

The years 1960 and 61 were packed with the lectures of many world famous physicists and mathematicians at the seminar. The year started with the visits of Abdus Salam and Niels Bohr both of which had a profound influence on the creation of MATSCIENCE and on my father's career.

Salam lectures at Ekamra Nivas: In January 1960, my father had an opportunity to organise a symposium on elementary particle physics at the Indian Science Congress in Bombay. He came to know that the eminent physicist Abdus Salam of Imperial College, London, was coming to India as an honored guest of the Congress. Since the members of the Seminar were well acquainted with Salam's fundamental work, my father invited him to participate in the symposium he was organising at the Congress and later give a lecture at his Seminar in Madras. Professor Salam graciously accepted the invitation and spent a few days in Ekamra Nivas.

Abdus Salam gave a magnificent two hour lecture at Ekamra Nivas on his work on weak interactions and was thrilled to find such an eager and enthusiastic audience. He enjoyed the delicious vegetarian dinner arranged by my mother for him and the members of the seminar. Following that he relaxed with the students on the lawns of Ekamra Nivas. Salam appreciated my father's work and efforts so much, that he invited him to a meeting of a small group of visionary scientists in Trieste later in the year to discuss the creation of the International Centre for Theoretical Physics (ICTP), and subsequently to the ICTP several times in the sixties.

Salam and my father became close friends and had a mutual admiration and respect for many things they had in common - the desire to create an environment that will foster high level scientific research, and to cherish the traditions of their homeland. My father presented Salam with a portrait of Lord Krishna which he accepted with grace; in return, my father expressed his appreciation by attending *Namas* with Salam at a mosque in Madras!

The visit of Niels Bohr and its impact: Salam's visit was immediately followed by that of Nobel Laureate Niels Bohr who was in India in January 1960 as the guest of Prime Minister Nehru. Professor Bohr accepted my father's invitation to visit Ekamra Nivas and meet the students of the Seminar. He was staying at the Govenment House, but agreed to have dinner at Ekamra Nivas and spend a leisurely evening with the students. He was accompanied by his wife and a deputy secretary of the Ministry of Scientific Research who accompanied him throughout India as his personal aide. In his honour my parents arranged a dinner on the front lawn of Ekamra Nivas, that was attended by many of the seminar students. While my mother conversed with Mrs. Bohr, my father was engaged in

discussions with Professor Bohr about the latest developments in theoretical physics and the prospects for research in Madras. I quote from my father's Diary -

"It was flattering that Professor Bohr and his wife stayed on until mid-night after an open air dinner on the lawns of Ekamra Nivas under the luscious foliage of the mango tree, in spite of repeated reminders from the official aide to get back to the Government House. Mrs. Bohr, a gracious woman of great charm and elegance, kept a watchful eye to prevent her husband from putting his burning pipe into his coat pocket! ....We could not believe that such a great physicist, engrossed in his own thoughts, who along with Einstein set in motion the atomic age, could evince interest in a group of stripling physicists in a far off country. He did so in a generous measure at a press interview at the airport which was reported in The Hindu in good detail as follows:

Dr. Bohr said that the Atomic Energy establishment was a mighty endeavour where research was being conducted in the very best way under the leadership of Dr. H. J. Bhabha, a scientist and at the same time a very good administrator.

Asked about the place mathematics should occupy in the pursuit of theoretical physics, the professor said that in Bombay and in Madras efforts were being made for the promotion of knowledge of physics which demanded new mathematical methods and the training of young people to be able fruitfully to contribute to such work. Wonderful work was being done in the field of theoretical physics by Professor Alladi Ramakrishnan of the Madras University.

He seems to have mentioned this to the Prime Minister when he met him before leaving India. "

My father soon received a communication from the Prime Minister's Office to supply further information about his efforts in Madras. It was to take nearly two years before this interest from the Prime Minister's office would lead to the creation of MATSCIENCE. And during these two years, the Seminar hosted several scientists of world repute in rapid succession, and my father continued his efforts to convince the government authorities for the creation of a new institute for fundamental research in the mathematical sciences.

Conclusion of assignment in Madurai: With the endorsement given by Professor Bohr, my father took courage and wrote to the Vice-Chancellor that it would be impossible for him to continue the assignment in Madurai. He had received an invitation from Andre Mercier to visit the University of Berne, Switzerland, for two months. So in that same letter, he requested the Vice-Chancellor for a two month leave to visit Europe. The Madras University sanctioned the leave and reluctantly agreed to relieve my father of the assignment in Madurai, and stated that he would return to Madras after the Swiss assignment as a "Professor without portfolio".

Prior to the departure to Switzerland in April, my father hosted Professor Cristoff of the University of Sofia, Bulgaria, in February, and Philip Morrison of MIT in March. Professor Morrison stayed at Ekamra Nivas. He was quite excited interacting with a group of enthusiastic students at the seminar who had been trained in quantum mechanics and relativity as in the ivy league universities in America.

The trip to Europe in 1960 was just as significant as my father's round-the-world tour of 1956 because of its influence on the Theoretical Physics Seminar and the creation of MATSCIENCE. So we describe this next.

Trip to Europe, April - June, 1960: My father departed Madras on 22 April, 1960 for Switzerland. Since Berne was not an international airport, he arrived in Zurich, and used the opportunity to meet Professor Heitler, to discuss the progress on the book on cosmic rays that Heitler had invited my father to write. From Zurich he went to Berne to take up his two month assignment.

At the University of Berne, my father gave a series of lectures on stochastic processes, scattering theory, and his new interpretation of the Feynman formalism. There he met Professor Wouthysen who was intrigued by these lectures and invited my father to a lecture at CERN on Feynman paths and stochastic processes. Interestingly, during the visit to CERN, my father met the Madras University Vice-Chancellor Dr. A. L. Mudaliar who happened to be in Geneva, and talked to him about initiating a visiting scientists programme at the University of Madras. This turned out to be a futile effort.

During his stay in Berne, my father made visits to other universities in Switzerland to meet and discuss with various scientists. One of them was Philip Casimir the Director of Philips. At the meeting of the Swiss Physical Society, my father had discussions with Professor Stueckelberg who was known in the world of physics as the forerunner of Feynman. On completion of the stay in Berne, my father returned to Zurich to fly out from there, but before departing Switzerland he met Professor Heitler and invited him to Madras.

From Zurich my father left for England by air arriving first in London where at the invitation of Professor Salam, he lectured at the Imperial College on his new viewpoint of Feynman graphs. He then made a side trip to Oxford for discussions with Captain Maxwell of the Pergamon Press to report on the progress being made on the book on cosmic rays that he was writing. While at Oxford, my father gave a seminar at Clarendon College. That night Professor D. G. Kendall invited him to a High Table dinner at Magdalene College. Following that was a visit to Harwell at the invitation of Professor Lane. My father lectured on hyperfragments at Harwell and had fruitful discussions with Professor Skyrme who later was one of the first visitors to MATSCIENCE.

From England my father left for Copenhagen where he visted Bohr's Institute of Theoretical Physics and attended the Symposium on Nuclear Structure. There were 28 participants in that Symposium, all of whom had spent some time at the Copenhagen Institute previously. Professor Bohr invited my father to dinner at his beautiful mansion where he met Nobel Laureate Professor Jensen.

The next stop was Paris where my father lectured at the Institute Henri Poincare at the invitation of Professors Kichenassamy and Madame Tonelat. Following the visit to Paris, my father went to Marburg to meet Professor Flugge and report on the progress of the article for the Handbuch der Physik. In Marburg he lectured on cascade theory and Feynman graphs.

It was while in Marburg, that my father received a telegram from Professor Dallaporta inviting him to a conference in Trieste, Italy, at the lovely Castle Miramare. There my father gave a one and half hour talk on the Feynman formalism to a group of eminent physicists including Salam and Fubini. It was at that conference that Abdus Salam proposed the creation of the International Centre for Theoretical Physics (ICTP) to a group of visionary scientists including my father. Later when this proposal for the ICTP was formally circulated to scientific societies around the world, and to certain notable scientists

for their opinion, the official representative of the Indian scientific community objected to its creation saying that it would we detrimental to the development of scientific research in India. And today, hundreds of Indian scientists visit the ICTP and benefit from its programmes. On receiving this negative reaction from the Indian scientific representative, Salam contacted my father, sent him the response from India to the proposal for the ICTP, and asked if my father could help. My father wholeheartedly supported Salam's proposal for the ICTP.

The visit to Trieste concluded a successful visit to Europe. My father returned to resume his position at the University of Madras since the Vice-Chancellor had relieved him of his assignment in Madurai.

Resumption of duties at Madras University: My father was considered by the University as a "Professor without portfolio" and was not given an office. But he was permitted to lecture in the German class room. His address was "Professor of Physics, c/o the German class room"! This ill treatment did not deter him since he could spend more time at Ekamra Nivas and attend to the Theoretical Physics Seminar and invite scientists to lecture there. One such visitor in July 1960 was the mathematician Arthur Copeland from the University of Michigan, who was an authority on the foundations of probability. He expressed sincere appreciation for the work of my father on product densities and for the students of the Seminar in pursuing its varied applications. It appeared as if Professor Heitler would visit as well, but he postponed his visit to 1961.

One of the students who joined the Theoretical Physics Seminar in July 1960 was K. Raman who had started his MSc Physics course in 1960-61. Raman completed his PhD in 1964 after the creation of MATSCIENCE. He played an active role in the Seminar as well as in the early years of MATSCIENCE by preparing notes of lectures by several distinguished visiting scientists.

Back from Europe, my father started to work in earnest on his book "Elementary particles and cosmic rays" for the Pergamon Press and encouraged his students to work with him on its chapters. He made several trips to Delhi to contact Dr. Laroia of the UGC and Minister Humayun Kabir of the Department of Scientific Research, both of whom were sympathetic to, and supportive of, his efforts in Madras. One more year had to pass before the miracle would happen.

The Seminar must go on: At the start of 1961, my father focussed his attention in completing his book "Elementary particles and cosmic rays" and submitted it to the Pergamon Press for publication. He also completed a paper with his student N. R. Ranganathan on stochastic methods in quantum mechanics which appeared later that year in the Journal of Mathematical Analysis and Applications. He resumed the MSc classes at Madras University with a course on Nuclear Physics. He lectured at Ekamra Nivas on the Mandelstam representation and the analyticity of scattering amplitudes. These lectures at home in January were augmented by those of his students S. K. Srinivasan on Geoffrey Chew's bootstrap theory, T. K. Radha on superconductivity, and Balachandran and Deshpande on strange particles. Thus a broad arena of modern physics was covered in the seminar talks.

In January my father received an invitation from Delhi to be a full time member of the Hindi Language Commission. But he could not serve on it full time, and so he accepted to

be a part time member in order to visit Delhi to feel the pulse of academic decisions being made in the capital. In the end it was not the administrative set up in Delhi that came to his support, but the far sighted Prime Minister and the visionary Minister of Education C. Subramaniam in Madras.

A visitor to the Seminar on 18 January 1961 was Kampe de Ferier from France who first lectured at the Madras University on the theory of turbulence. That evening when he visited Ekamra Nivas, there was an active discussion with him on random functions at the Seminar. This led my father to study strong interactions with the hope of understanding the analytical properties of scattering amplitudes. A few days later, Prof. W. W. Brueckner of the Massachussets Institute of Technology arrived in Madras as part of a technical delegation from that great institution. He found time to come to Ekamra Nivas for Tea and for a leisurely discussion with the students. Around the same time, Prof. K. A. Brueckner of UCSD who had formed a positive opinion of the work of Vasudevan, wrote again offering another post-doctoral fellowship to any one student of my father's choosing. My father recommended his female students R. Thunga and T. K. Radha for fellowships at Brueckner's group at the University of California in San Diego.

Professor Heitler who had postponed his trip to Madras, arrived in early February. But at that time my father had to fly to Trivandrum since my maternal grandfather was seriously ill. Yet, it was arranged during 3-6 February for Heitler to give two lectures at Ekamra Nivas to the students on "The finite size of elementary particles". This only goes to prove, that no matter what the personal difficulties were, my father was committed to keep the Seminar vibrant and undisturbed.

In February and April 1961, within a span of a few weeks, both of my mother's parents passed away. It was a deep tragedy for the family, and especially to my mother. Since she had no brothers, my father performed the obsequies. Yet, in between the domestic tragedies, my father participated in two symposia - one in Bombay at the TIFR and another in Chandigarh, and took a batch of his students to both these meetings. At Chandigarh he lectured on Feynman kernels. Seminars continued at Ekamra Nivas with talks by several students - Devanathan on Feshbach's theory of nuclear reactions, Balachandran on covariant formalism, and Bhamathi on parity questions. Also during this period, my father wrote up several papers with his students, many of which appeared later in the year, a notable one being the joint work with T. K. Radha on correlation problems in evolutionary stochastic processes that was published in the Proceedings of the Cambridge Philosophical Society.

In March the Mathematics Review Committee of the University Grants Commission, of which my father was a member, submitted its report on the development of mathematics. While other members of the Committee recommended the creation of advanced centers *within* universities, my father insisted that there should be provision for creating institutions *outside* universities. My father says in his Diary: "Though my dissent was not formally included in the report, it turned out to be prophetic by the creation of MATSCIENCE at the end of the year."

On April 4, the great mathematician Marshall Stone of the University of Chicago arrived and was a guest of my father at Ekamra Nivas. He came as a member of an international committee for the development of mathematics in India. At the Madras

University he gave a research seminar on Hilbert space methods in conformal mappings, as well as a general lecture on the teaching of algebra in high schools. Professor Stone was not only an outstanding mathematician, but a great administrator. As Chairman he transformed the mathematics department at the University of Chicago so significantly, that the period he was Chairman is referred to as the "Stone Age"! Thus with his interest in contributing to the profession, he could appreciate my father's efforts in Madras. Professor Stone was the son of a Justice of the US Supreme Court. Thus he could understand my father's family background as well. Over the years, Stone and my father shared a deep friendship. He visited MATSCIENCE many times, on one occasion as Ramanujan Visiting Professor, and later for the inauguration of the new building for the Institute in 1969 when he delivered the first lecture there.

On April 10 my father received a letter once again from Prof. K. A. Brueckner of UCSD offering another post-doctoral fellowship to any one student of my father's choosing. Prof. Brueckner had formed such a positive opinion of the work of Vasudevan, that he wrote again offering another post-doctoral position. This time my father recommended his female students R. Thunga and T. K. Radha for fellowships at Brueckner's group at the University of California in San Diego.

In May my father attended a Summer School in Dalhousie with his students V. Devanathan, K. Venkatesan, and G. Ramachandran. He gave three lectures in Dalhousie on the physical basis for quantum field theory; his paper on this topic co-authored with Radha and Thunga appeared in the Journal of Mathematical Analysis and Applications a year later.

The reputation of the Theoretical Physics Seminar was so high in the Madras academic circles that the very best students desired to join the Seminar. In the summer of 1961, K. Ananthanarayanan who had secured the Madras State First Rank in MSc Mathematics, enrolled under my father for a PhD and started attending the Seminar. The next year, soon after the creation of MATSCIENCE, T. S. Santhanam who obtained the State First Rank in MSc Physics, enrolled for his PhD under my father. Anantha received his PhD in 1965 and then was a post-doc at Stanford during 1966-67. He was at MATSCIENCE until 1969 when he left for another post-doctoral position in Montreal. He then settled down in California as a Professor at San Diego State University. Santhanam rose to the rank of Professor at MATSCIENCE where he stayed until the mid-eighties when he left for St. Louis, USA on a professorship.

In June 1961, Minister C. Subramaniam was leaving for the United States and on the same day, Ranganathan was leaving for Boston for an assignment at Brandeis University. My father called on C. Subramaniam one day before his departure, and CS showed considerable interest in starting a new institute. My father suggested that in the United States, CS should meet a few leading scientists and get their opinion about the Theoretical Physics Seminar and the need for a new institute in Madras. When Mr. Subramaniam returned from his US tour in August, he conveyed to my father the positive impressions about the theoretical physics seminar that were expressed by the eminent scientists. These impressions reaffirmed the desire of Mr. Subramaniam to start an institute along the lines suggested by my father.

The visit of Gell-Mann and Dalitz: During 19 June to 11 July 1961, a Summer School was organized in Bangalore by the Tata Institute with Murray Gell-Mann and Richard Dalitz as the main lecturers. My father attended this summer school and took with him eight of his students including the four lady students - Radha, Thunga, Indumathi and Bhamathi. My mother and I accompanied my father on this trip to Bangalore and I have pleasant memories of excursions to Nandi Hills and to Krishna Raja Sagar with Gell-Mann and Dalitz.

In his lectures Gell-Mann introduced his now famous unitary symmetry for which he later won the Nobel Prize. Dalitz gave lectures on the *tau-theta puzzle*. My father was impressed by the dynamic delivery of Gell-Mann and the thoroughness of presentation of Dalitz. Toward the end of the Summer School, my father invited Gell-Mann and Dalitz to spend a few days at Ekamra Nivas and they graciously accepted the invitation. My father says in his Diary: "The impact of their stay for a few days on my scientific career was greater than that due to years of conventional education! The admiration of Dalitz for Gell-Mann was so great that sometimes he wondered whether it was worth pursuing research when Gell-Mann was striding the world like a colossus. I did not share this view of Dalitz since I was hopeful of doing something on the fundamental problems that engaged the attention of Feynman and Gell-Mann....

I took Gell-Mann to meet our Vice-Chancellor, having informed him that Gell-Mann was a legend in a country that does not easily accept legends. The interview between a venerable Vice-Chancellor whose power over the University was so great and the young Gell-Mann whose influence on science was universal, was watched by me with anxious interest....After Gell-Mann and Dalitz left, we tried to reproduce their lectures in a course of twelve talks in the Theoretical Physics Seminar." These talks were given by Indumathi and Bhamathi.

Soon after the visit of Gell-Mann and Dalitz, my father received a letter from Vikram Sarabhai requesting that him to take care of the distinguished cosmic ray physicist Arne Sandstrom from Uppsala, Sweden who was to visit Madras. Thus Sandstrom was the next visitor to the Seminar and he enjoyed a relaxed evening (July 29) with the students over dinner at Ekamra Nivas. My father also had arranged earlier that afternoon a talk on Cosmic Radiation by Professor Sandstrom at the All India Radio. My father always believed that it is important to inform the public at large about the developments in science, and over the years he gave several talks for the All India Radio and arranged for some of his foreign guests to speak there as well.

The visits of Glaser and Shapiro: The months of August and September saw the visits of Nobel Laureate Don Glaser from Berkeley and the cosmic ray physicist Maurice Shapiro of the US Naval Research Labs.

Glaser had won the Nobel Prize in 1960 for his discovery of the Bubble Chamber and so his visit to Madras was just a few months after that. His visit was just for 24 hours (August 13-14)- he made a stop in Madras on his way from Bangalore to Columbo. After my parents received him and his wife at the Madras airport, they took them on an excusrion to Mahabalipuram which the Glasers enjoyed immensely. The next day Professor Glaser spent the morning at Ekamra Nivas (Aug 14). My father gave him an overview of the work being done by his students who then made some individual presentations -

especially Devanathan and Balachandran. Professor Glaser enjoyed discussions with my father and his students and made several helpful suggestions. Later that day, before his departure to Columbo, Professor Glaser was taken by my father to meet the Vice-Chancellor. Thus at every possible occasion, my father attempted to arrange meetings between the distinguished visitors and the Vice-Chancellor in the hope that eventually something positive would come out of such meetings.

In late August, Deshpande who had completed his MSc in Physics and had been an active member of the Seminar, left for the Philadelphia to pursue his PhD there. My father encouraged him in his efforts to seek opportunities in the United States. Deshpande settled in America after his doctorate and took up a Professorship at the University of Oregon.

In early September my father received a handsome invitation from Richard Bellmann to the Rand Corporation in California on terms "just as you wish". Due to commitments in Madras, my father could not accept that invitation rightaway. However, after MATSCIENCE was created in 1962, he made a Round-the-World academic tour in which the major component was a two month visit to RAND in September-October 1962.

Maurice Shapiro whom my father had made acquaintance with in 1957-58 during the stay in Princeton, came to Madras on September 24 after attending a conference in Kyoto. He gave a two hour talk at Ekamra Nivas on September 25 giving a report of the Kyoto conference. C. Subramaniam had just returned from his trip to America, and related to my father the favourable comments on the Theoretical Physics Seminar made by several eminent scientists there. Spurred by this positive report, my father urged Mr. Subramaniam to meet Shapiro. Actually Shapiro had met the Vice-Chancellor earlier in the morning, but the meeting with Subramaniam the same evening was more fruitful because my father made a gamble for the launch of a new theoretical physicist institute. My father notes in his Diary: "Shapiro told C. Subramaniam that watching the students at work at Ekamra Nivas reminded him of the manner in which scientists gathered around Oppenheimer at Los Alamos! That was a high and generous tribute which made a great impression on Subramaniam. Shapiro went on to suggest that the students should meet the Prime Minister of India." This comment from Shapiro made Subramaniam write to Jawaharlal Nehru suggesting such a meeting.

Historic meeting with Prime Minister Nehru: On 30 September 1961, my father received a telegram from C. Subramaniam in Delhi, saying that the Prime Minister was willing to meet the members of the Theoretical Physics Seminar on October 8. My father had been waiting for that great moment and it had arrived. He broke the news to the students of the Seminar who could not believe their ears. The four lady students who had plans to visit the Indian Statistical Instituite in Calcutta from October 2 onwards, postponed their trip to October 10 in order to meet the Prime Minister.

The meeting was arranged at the Governor's Residence, the Raj Bhavan, where the Prime Minister was staying. My parents were invited to an official dinner with the Prime Minister and the meeting with the students was after the dinner at 9:30 pm. Mr. C. Subramaniam was present both at the dinner and at the 9:30 pm meeting. To capture the mood of the moment, I quote my father from his Diary: "I hardly need describe my trepidation and anxiety, for so much was to depend upon a few minutes of conversation

- almost the dreams and aspirations of a whole scientific community hung on the smiling lips of our Prime Minister. Ten minutes before the close of the dinner, he summoned me and all the students to have a personal interview wit him. It was a strange feeling for me to do all the talking with a man who had held unquestioned sway over the deastiny of our country. At the end he asked me only one question - "Are you really convinced that we should have an Institute of the kind you are insisting upon?" I naturally said 'yes' with all the emphasis at my command, and he just smiled."

My father was then asked by Mr. Subramaniam to send a formal proposal which he would discuss with the Prime Minister. I now quote from the chapter on Mathematics in Mr. Subramaniam's autobiography *The Hand of Destiny*:

"Ramakrishnan mentioned to me that for the purpose of encouraging young talent in theoretical physics and mathematics, a new institution was necessary. At that time the entire research work in mathematics and theoretical physics was done only in the Tata Institute of Fundamental Research (TIFR) in Bombay under the auspices of the Atomic Energy Commission (both headed by Dr. Homi Bhabha). Ramakrishnan emphasised the need for another institute so that there might be some competition... instead of one institute monopolising the entire research work. But another institute could be started only with the concurrence of Atomic Energy Commission and the Government of India....

Jawaharlalji was greatly impressed by the enthusiasm shown by the students (of Professor Ramakrishnan)... and in particular to see four girls among the students. When the students told him that they needed an institution for the development of theoretical physics and mathematics, he asked me to examine the proposal and put up a note for his consideration. Ramakrishnan prepared a note for the purpose and I sent it to the Prime Minister."

It was to take two more months for the Prime Minister to give a nod for the creation of a new institute, and I will describe the discussions in New Delhi a bit later. Meanwhile, during these two months, there were other events happening including the visits of several distinguished visitors to the Seminar, and I will describe this now.

On October 12 , my father recived a letter from Professor Schiff, inviting him to Stanford University for a fortnight. My father availed this invitation in 1962 and visited Stanford after spending two months at RAND. The very next day, my father received a letter from Professor Thirring offering Balachandran a post-doctoral fellowship.

The visits of Chandrasekhar, Lighthill and Hazzlett: During October 24-25, my father had to make a visit to Delhi, and while there, he met Dr. Kothari. But Kothari was emphasizing the creation of new centres within universities and so that proved to be on no avail. My father also had meetings in Delhi with Humayun Kabir, the Cabinet Minister for Scientific Research and Dr. Loraia of the University Grants Commission, with whom he repeatedly made a case for a new institute outside of a university, not knowing who would help in the ultimate decision by the Government to launch an institute. The great astrophysicist Subrahmanyam Chandrasekhar was in Delhi at that time, and my father invited him to visit Ekamra Nivas to meet the students.

Chandrasekhar gave a series of lectures at the Madras University (Nov 6-17) on various topics including gravitation and cosmic magnetic fields. He jokingly insisted that he would visit Ekamra Nivas only if he would be treated to a typical South Indian style plantain leaf

dinner, which of course was no problem for my mother to arrange. Chandrasekhar gave a two hour lecture at Ekamra Nivas on November 8 and was in his typical full suit. He visited Ekamra Nivas again on November 13 and took an active interest in my father's theoretical physics group and in discussions with them. Balachandran and Radha presented their work to Professor Chandrasekhar. On November 15 there was a South Indian dinner for Chandrasekhar and his wife at Ekamra Nivas and all the students were invited to join. He the changed into a *dhothi* to enjoy the plantain leaf dinner! He visited Ekamra Nivas again on November 18 and gave a three hour lecture to the students on the negative hydrogen ion and on general relativity. It is said of Chandrasekhar that his commitment to lecture to dedicated students was so great, that he would make an hour long trip from Yerkes Observatory to the University of Chicago to lecture to a class of just two students - T. D. Lee and C. N. Yang; that effort was well worth it, because both these students won the Nobel Prize a few years later! Chandrasekhar's dedication to talk to eager and talented students was demonstrated by his many visits to Ekamra Nivas for lectures and discussions.

In late November -early December, there were two more visitors to Ekamra Nivas - McCrea Hazzlett, the Vice-President of the University of Rochester, and M. J. Lighthill, Director of the Royal Aircraft Establishment in Farnborough. Hazzlett's visit (Nov. 23) was prompted by the eminent physicist Robert Marshak of the University of Rochester, who thought highly of my father's efforts to intoduce modern physics to the students in Madras. Later as President of the University of Rochester, Hazzlett visited MATSCIENCE in January 1964 and inaugurated its Second Anniversary Symposium.

My father's acquaintance with Lighthill dated back to his graduate student days at Manchester, and so it was a pleasure for him to host an old friend in Madras. Lighthill gave a two and half hour lecture at Ekamra Nivas. Mr. Subramaniam joined Lighthill for dinner at Ekamra Nivas on December 3, 1961 and on that day my father made a final appeal to the Minister for a new institute. The decision to launch the institute was only a week away. To give a proper account of that, I need to describe what was going on in Delhi with regard to my father's formal proposal to the Prime Minister. For that I will quote from Mr. Subramaniam's autobiography, because he was a direct witness to the meetings in Delhi and played a crucial role in swaying the decision of the Prime Minister in my father's favour.

Decision to create MATSCIENCE

The winds were favourable. Mr. R. A. Gopalaswami, Chief Secretary of the Government of Madras, with his strong leaning towards the mathematical sciences, asked my father on December 5 to formulate the aims and objectives of the proposed institute, at the suggestion of Mr. Subramaniam. My father was ready for this crucial moment and supplied the requested document the next day. Meanwhile, in New Delhi, the Prime Minister had begun seeking opinions on the the initial proposal for the creation of a new institute that my father had sent him through Mr. Subramanian soon after the meeting with the Prime Minister at the Raj Bhavan on October 8. There were two aspects in which Mr. Subramaniam played a crucial role in the ultimate decision: The first was to convince the Prime Minister that a new institute was necessary as my father had proposed. The second was that it should be in Madras. I quote from the chapter on Mathematics in Mr.

Subramaniam's autobiography, *The Hand of Destiny*:

"The Prime Minister referred the matter to Dr. Homi Bhabha for his advice. Unfortunately, Dr. Bhabha was not very enthusiastic. His contention was that the available limited resources would have to be utilised for the existing institution, namely, the Tata Institute of Fundamental Research (TIFR).

When the Prime Minister passed on the opinion of Dr. Bhabha to me, I requested him to arrange a meeting between me, Dr. Bhabha and himself to discuss this matter. The meeting was arranged and I argued my case for a separate institution in the South, particularly when talented students in the South were not getting opportunities for pursuing their interests because of the limited number of students admitted to TIFR. I also emphasised that mathematical sciences did not require heavy investment. Panditji also showed his inclination to accept my point of view. So Dr. Bhabha also gave his consent. Thereafter steps were taken to establish what is now well known as the Institute of Mathematical Sciences....For the purpose of emphasising the importance of this Institute, and for its proper funding, I thought we should have Jawaharlal Nehru himself as the Patron of the Institute. When I mentioned this to him, he gladly agreed. I requested Dr. Bhabha to be a member of the first Governing Body of the Institute (and he agreed)."

With the approval given by the Prime Minister, steps were taken in a rapid pace to create an Institute in the next two weeks. To capture the mood of that trilling moment, I quote from my father's memoirs:

"The 7-th of December was a significant day when I met Mr. Subramaniam and the Chief Secretary, both of whom agreed to the creation of the Institute. Meanwhile seminars were going on with unabated vigour in Ekamra Nivas....

Meanwhile, the Annual Symposium on Cosmic Rays under the auspices of the Department of Atomic Energy was arranged in Madras and inaugurated by the Vice-Chancellor Sir. A. L. Mudaliar. I was in charge of the arrangements of the symposium, which I carried out as best as I could, but my mind was set on the new institute.

On the 20th of December I met C. Subramaniam at the Madras airport on his return from Delhi. What a thrilling moment it was when he informed me that the Prime Minister had agreed to be the Patron of the Institute!

December 22 was a day of dedication in my career. At 1:30 pm, I was called by the Education Secretary Mr. K. Srinivasan, who issued an order of appointment to me as the Director of the Institute. What a providential coincidence that it should be the birthday of Srinivasa Ramanujan! I met the great astrophysicist Subrahmanyam Chandrasekar (of the University of Chicago) the same evening to inquire whether he could inaugurate the Institute on January 3, 1962. He agreed to do so provided we obtained suitable air reservations for him (to return to the United States) the next day. What a simple request from so great a man!"

For the Cosmic Ray Symposium, my father assigned much of the organizational work to K. Raman, his PhD student. There were eighteen talks of varying lengths at the Cosmic Ray Symposium by the students of the Theoretical Physics Seminar which testifies to the high level of activity by my father's students on cosmic rays and related topics. On December 22, my father had arranged a music concert by my mother's sister Mrs. Kamala Kailasanathan, in the Seminar Hall of Ekamra Nivas for the delegates of the Annual Sym-

posium on Cosmic Rays. That concert originally intended for the symposium delegates, turned out also to be a celebration of the news about the launch of MATSCIENCE!

The next day my father tended his resignation to the University of Madras.

Time was short with barely ten days remaining for the inauguration. Overnight, more than a hundred letters were typed by my father's secretary Mr. Nambi Iyengar and sent to scientists all over the world announcing the launch of MATSCIENCE, The Institute of Mathematical Sciences. From December 27 onwards, telegrams started pouring in from Nobel Laureates and other eminent scientists heralding the creation of the new Institute and congratulating my father on his appointment as its Director. These congratulatory messages included several from Nobel Laureates - Niels Bohr, Werner Heisenberg, P. A. M. Dirac, Neville Mott, Donald Glaser, and Hideki Yukawa, as well as from soon to be Nobel Laureates - Richard Feynman, Murray Gell-Mann, and Abdus Salam.

I remember a dinner at the roof garden of Hotel Dasaprakash on Christmas Day, December 25, hosted by the students of the seminar in honour of my father just before the launch of MATSCIENCE. At that dinner my father asked each student to predict the number of congratulatory telegrams that would be received by the time of the inauguration. Such was the exciting mood of the moment.

The inauguration of MATSCIENCE

I begin by quoting my father, because it conveys best the mood of that magic moment:

"What a thrill and excitement it was to greet the New Year (in this fashion), and for the Institute to be inaugurated on the 3-rd of January by Professor S. Chandrasekhar at a public function presided over by its primary supporter Mr. C. Subramaniam. I could not sleep the whole night as cablegrams of greetings were being delivered every hour and through the night from various parts of the world. I was too excited to prepare my inaugural speech, and I decided to deliver it extempore under the inspiration of the exalted moment.

The Institute was inaugurated at 9:00 am on the Old English Lecture Hall of the Presidency College where I had listened to many lectures during my study in the Honours Course. I gave my speech in tears of joy and gratitude to Providence for a dream fulfilled. ....It was a reflection of the past, an estimate of the present, and a peep into the future of science in India.

It was a day of prayerful dedication, when I thought of my parents who should have been there with us in 'our finest hour'. Among the happiest persons were Lalitha who shared my hopes and sustained my efforts, and Krishna, who understood the spirit of the hour in equal measure."

My father was an orator par excellence, and I have enjoyed hearing many of his outstanding lectures and speeches over the years both in India and abroad. His speech "The Miracle has Happened" (see Appendix) at the inauguration of MATSCIENCE, was the finest he delivered in his life! As a six year old boy, I was in the front row at the Old English Lecture Hall listening to this speech which still resonates within me. The speech was delivered extempore, as was his style, and later reproduced from a recording.

The academic work of the new institute began immediately with a lecture by Professor Chandrasekhar on gravitation in the physics lecture room where he and his illustrious uncle

Nobel Laureate Sir. C. V. Raman had studied as undergraduates. MATSCIENCE was initially given two rooms in the Presidency College where it functioned for two years before moving to the Central Polytechnic Campus in Adyar in April 1964.

There was a steady stream of visitors right from the start, now coming at the invitation of MATSCIENCE. Some of the first visitors were Professors Skyrme of the Atomic Energy Establishment in England who spoke on non-linear field theory, Ugo Fano of the National Bureau of Standards in Washington DC, Claude Bloch of Saclay, France, and Bourgin of the University of Illinois at Urbana.

All members of the Theoretical Physics Seminar as on January 1962 joined the new Institute at various levels – R. Vasudevan, N. R. Ranganathan, T, K. Radha, G. Bhamathi, S. Indumathi, R. Thunga, V. Devanathan, G. Ramachandran, K. Venkatesan, A. P. Balachandran, K. Ananthanarayanan, K. Raman, and R. K. Umerjee. They all continued to give seminars vigorously in the new premises of the Institute. But from time to time, my father and his students held seminars in the evenings at Ekamra Nivas for a few years after the creation of the Institute. My father's former students P. M. Mathews and S. K. Srinivasan had appointments at Madras University and IIT, Madras, respectively after completing their PhDs in 1956 and 57. Vasudevan was at UCSD on an extended post-doctoral fellowship and so was not present at the inauguration; he returned in 1963 and joined the Institute as Permanent Member. Ranganathan was at Brandeis University on a post-doctoral fellowship; he returned in 1963 to join MATSCIENCE. Thunga got married in September 1962 and so left the Institute to settle down with her husband in New York. At my father's recommendation, A. P. Balachandran received a post-doctoral fellowship at the University of Chicago under Dalitz which he accepted. Meanwhile Professor Thirring had offered Balachandran a fellowship for six months in Vienna, and my father obtained a special permission from the Vice-Chancellor to allow him to leave before submitting his thesis. So Balachandran left a few months after the inauguration of the Institute. He settled in the United States. My father always felt that scientific research was an international enterprise, and never prevented his students from pursuing careers overseas. Such large heartedness is rare among administrators. In an Appendix, I indicate the career paths of the students of the Theoretical Physics Seminar after they received their PhDs.

Perhaps the first few years of the Institute were the finest in terms of vibrancy of the Visiting Scientists Programme. Professor Rosenfeld who visited the Institute in 1963 expressed wonder on how so much was being done in such modest surroundings and with an even more modest budget. Rosenfeld said that in every place in Europe where he had been recently, there was someone who had visited, or was intending to visit, MATSCIENCE.

The Institute was formally registered on Friday, July 13, 1962. The Institute moved to more spacious accommodation on the top floor of a building in the Central Polytechnic Campus in 1964, and finally to its own premises in 1969 where it continues to function today. From its modest initial budget of Rs. 5000, it has grown in size to a multi-crore project in fifty years, like a banyan tree growing out of a small seed. Thus as we celebrate the current status of the the Institute in the world of science, it is necessary and important to realize its humble beginnings, and the enormous efforts of its Founder Professor Alladi Ramakrishnan who created this jewel literally out of a vacuum, by his vision and perseverance. In this effort, the participation of talented students in the Theoretical Physics

Seminar was the crucial component. This effort was appreciated by several scientists of world repute and it was that positive opinion from such luminaries that convinced the Prime Minister Jawaharlal Nehru and Education Minister C. Subramaniam to launch the new institute. It should be a matter of pride to look back at origins of the Institute as we celebrate fifty years of its achievement. I am happy and proud to have been given an opportunity to describe all this at the Golden Jubilee Conference of MATSCIENCE.

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4) C. Subramaniam, *The Hand of Destiny, Vol I*, Bharatiya Vidya Bhavan, Bombay (1993), pp 320-321.

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APPENDIX I

DISTINGUISHED SCIENTISTS WHO VISITED ALLADI RAMAKRISHNAN'S HOME AND THE THEORETICAL PHYSICS SEMINAR, 1954-61

1. **Professor P. A. M. Dirac**, F.R.S., Nobel Laureate
Lucasian Professor, Cambridge University, England (Dec 1954)

2) **Professor Mark Oliphant**, F.R.S. (he was later knighted and became Governor of South Australia)
Australian National University, Canberra (Jan 1955)

3) **Professor C. F. Powell**, F.R.S., Nobel Laureate
Melville Wills Professor of Physics, Unibersity of Bristol, England (Dec 1955)

4) **Professor Cherry**
University of Melbourne, Australia

5) **Professor Harry Messel**
Nuclear Science Foundation, University of Sydney, Australia (Jan 1957)
medskip
6) **Professor W. W. Brueckner**
Massachussets Institute of Technology, USA

7) **Professor T. G. Room**, F.R.S.
University of Sydney, Australia

8) **Professor Laurent Schwartz**, Fields Medalist
University of Paris, France

9) **Professor H. Pitt**, F.R.S.
University of Leeds, England

10) **Sir. C. G. Darwin**, F.R.S.
Former President, Royal Society, England

11) **Professor L. Janossy**
Director, Eotvos Institute, Budapest, Hungary (Jan 1959)

12) **Professor S. Koba**
Yukawa Hall, Kyoto, Japan

13) **Dr. T. Kotani**
University of Tokyo, Japan

14) **Professor Andre Mercier**
University of Berne, Switzerland (Sept 1959)

15) **Professor N. Dallaporta**
University of Padova, Italy (Oct 1959)

16) **Professor A. M. Lane**
A.E. Research Establishment, Harwell, England (Dec 1959)

17) **Professor George Gamow**
University of Colorado, USA (Dec 1959)

18) **Professor Abdus Salam**, F. R. S. (Salam later won the Nobel Prize)
Imperial College, London, England (Jan 1960)

19) **Professor Niels Bohr**, Nobel Laureate
Bohr Institute of Theoretical Physics, Copenhagen, Denmark (Jan 1960)

20) **Professor Christoff**
University of Sofia, Bulgaria (Feb 1960)

21) **Professor Phillip Morrison**
Cornell University, Ithaca, USA (Mar 1960)

22) **Professor A. H. Copeland**
University of Michigan, Ann Arbor, USA (July and Dec 1960)

23) **Professor Kamp-de-Feriet**
University of Lille, France (Jan 1961)

24) **Professor W. Heitler**, F.R.S.
University of Zurich, Switzerland (Feb 1961)

25) **Professor Marshall H. Stone**
Distinguished Service Professor, University of Chicago, USA (Apr 1961)

26) **Professor Hlavaty**
Institute of Fluid Dynamics, Indiana, USA

27) **Professor Murray Gell-Mann** (Gell-Mann later won the Nobel Prize)
California Institute of Technology, USA (summer 1961)

28) **Professor R. A. Dalitz**
University of Chicago, USA (summer 1961)

29) **Professor Sandstrom**
Uppsala University, Sweden (July 1961)

30) **Professor Donald Glaser**, Nobel Laureate
University of California, Berkeley, USA (Aug 1961)

31) **Dr. Maurice Shapiro**
Naval Research Lab., Washington, USA (Aug 1961)

32) **Professor S. Chandrasekhar** (he later won the Nobel Prize)
Distinguished Service Professor, University of Chicago, USA (Nov 1961)

33) **Professor M. J. Lighthill** (he was later knighted)
Director, Royal Aircraft Establishment, Farnborough, England (Nov 1961)

34) **Professor McCrea Hazlett**
Vice-President, University of Rochester, USA (Dec 1961)

STUDENTS OF PROFESSOR ALLADI RAMAKRISHNAN WHO ATTENDED THE THEORETICAL PHYSICS SEMINAR

1) K. Ananthanarayanan

2) A. P. Balachandran

3) G. Bhamathi

4) V. Devanathan (*acted as the Seminar Secretary*)

5) N. G. Deshpande

6) S. Indumathi

7) P. M. Mathews

8) V. Radhakrishnan

9) P. Rajagopal

10) B. Ramachandran

11) G. Ramachandran

12) K. Raman

13) T. K. Radha

14) N. R. Ranganathan

15) M. Srinivasan

16) S. K. Srinivasan

17) R. Thunga

18) R. K. Umerjee

19) R. Vasudevan

20) K. Venkatesan

21) V. K. Viswanathan

22) Vepa Ramesam

*) E. T. Nambi Iyengar (*helped with all academic correspondence and accounts.*)

LIST OF SEMINAR STUDENTS WHO RECEIVED THEIR PHD UNDER THE DIRECTION OF ALLADI RAMAKRISHNAN

The following is the list of students of the Theoretical Physics Seminar who obtained their PhD under Professor Alladi Ramakrishnan first at the University of Madras and later at MATSCIENCE. The year PhD was granted is given at the beginning.

1) (1956) **P. M. Mathews** (Had post-doctoral position in Brandeis in 1957-58. Became Head of the Department of Theoretical Physics at the University of Madras, India.)

2) (1957) **S. K. Srinivasan** (Was a post-doc in Sydney in 1957-58. Became Head of the Mathematics Department at the Indian Institute of Technology, Madras, India.)

3) (1960) **R. Vasudevan** (Became Professor at MATSCIENCE, Madras. Had post-doctoral fellowship at UCSD during 1959-63.)

4) (1961) **N. R. Ranganathan** (Post-doc at Brandeis University, USA during 1961-63. Became Professor at MATSCIENCE.)

5) (1962) **T. K. Radha** (Was at MATSCIENCE until her marriage in September 1966. Had a post-doctoral fellowship at Stanford in 1963. Held a Visiting Membership at the Institute for Advanced Study, Princeton in 1965-66.)

6) (1962) **R. Thunga** (Was at MATSCIENCE until her marriage in September 1962 after which she settled in New York. Was member of MATSCIENCE until 1963.)

7) (1962) **A. P. Balachandran** (Left Matscience in August 1962 for post-doctotal positions first in Vienna and then in Chicago (1963). Joined Syracuse University, USA in 1964 and subsequently became Professor there.)

8) (1963) **V. Devanathan** (Joined A. C. College University of Madras in 1957 and did his PhD. Later became Head of the Department of Nuclear Physics at the University.)

9) (1963) **K. Venkatesan** (Was at MATSCIENCE until 1969. Later became a faculty member at IIT Madras.)

10) (1963) **G. Bhamathi** (Became Head of the Department of Theoretical Physics at the University of Madras, India)

11) (1963) **S. Indumathi** (Was at MATSCIENCE in 1962; died a few years later.)

12) (1963) **G. Ramachandran** (Was at MATSCIENCE until 1965. Became Professor at the University of Mysore, India)

13) (1964) **K. Raman** (Was at MATSCIENCE until 1964. Had post-doc positions at Boston University (1964-65) and Syracuse University (1965-67). Joined the faculty at Brown University, USA in 1967)

14) (1964) **R. K. Umerjee** (Was at MATSCIENCE until 1965. Subsequently had post-doctoral positions in USA.)

15) (1965) **K. Ananthanarayanan** (Was at MATSCIENCE until 1969. Held post-doctoral positions at Stanford (1966-67) and in Montreal (1969-73). Became Professor at San Diego State Univ, USA.)

APPENDIX II

PROFESSOR ALLADI RAMAKRISHNAN'S SPEECH ON THE INAUGURATION OF THE MATSCIENCE INSTITUTE

My father Professor Alladi Ramakrishnan was a master of exposition, both in written and spoken form. He was a dynamic speaker, an orator in every sense. Right from my boyhood I had the pleasure to listen to many of his scientific lectures and speeches, and was inspired by his manner of speaking and the power of his oratory. The finest speech he ever gave was perhaps at the inauguration of MATSCIENCE, the Institute of Mathematical Sciences, on January 3, 1962, when his thoughts came pouring out at that very exciting and memorable occasion. As a seven year old boy, I was in the front row of the English Lecture Hall at the Presidency College in Madras when he delivered that speech extempore, as was his custom. The speech was later written up from a tape recording. The speech was printed in the appendix to The Alladi Diary, Vol I, East-West Books, Madras (2000). It is reprinted here with the kind permission of East-West Books. - Krishnaswami Alladi

The Miracle Has Happened

Alladi Ramakrishnan

So the miracle has happened. By the Grace of God and the will of man, a new situation has been brought into being which augurs to be the starting point of an intellectual renaissance, the nature and magnitude of which cannot be foreseen at the present time. It is incredible that a series of events, each as improbable as the other, should have taken place in such steady and rapid succession. It is as though a chapter of a book of fairy tales has been transmuted into real life and I feel like one who wakes up from a dream to find reality stranger than fantasy.

The dream is so chaste that I have the courage to ask all those present here to share it with me. It originated five years ago in the exotic atmosphere of the quaint old town of Kyoto in Japan where I spent six weeks at the invitation of Professor Yukawa. In the 'domestic' environment of the Yukawa Hall, young Japanese physicists, the hope and pride of their country, just resurrected from the second World War, gathered together in enlightened leisure to discuss the most abstruse problems of modern physics. That strange enchantment drew me into the domain of elementary particle physics and I played with the idea of creating something like the Yukawa Hall in my own home town where my great father made his legendary reputation in another field of intellectual activity.

The enchantment became a passion when a fortitutious circumstance took me to the New World and I had the opportunity to attend the Conference on High Energy Physics at the University of Rochester in the spring of 1956. Within four days I was brought face to face with the rising generation of American physicists. One had only to listen to Gell-Mann and Chew, Feynman and Goldberger, to realise that a new era in American physics had been ushered in. American institutions no longer depended on the guidance of European scientists as they did a decade ago, when due to the chance of war, they were able to offer hospitality to European physicists like Fermi, Segre, and Bethe. American physics leapt from infancy to manhood within this decade and it has now become almost

a necessity for European physicists to spend some time in the great American institutions and in the laboratories where things are happening every day and every hour. I felt that such a transformation needs to come in my own country which despite its organised efforts in scientific research has yet to take a place in creative science.

I therefore tried to analyse the causes for our failure. There has always been the conventional argument that there was not enough talent in the country which is not borne out by facts. It is a tragedy too deep for tears that we do not take cognisance of talent or creative work unless it has received recognition outside our frontiers. Sometimes the wait is too long, the response so cold, that it freezes up the all too frail impulses for academic life in our country. What we need is a new generation of scientists, impatient for opportunities, intolerant of mediocrity, full of action, full of manly pride and friendship like their compeers in the new world, who have not only faith in their powers, but in the scientific progress of their country.

I was strengthened in this faith during my stay, at the kind invitation of Professor Oppenheimer, in Princeton, where the most gifted minds in mathematical sciences gather together every year in an atmosphere exhilarating for creative work. It was a momentous year when the work of Yang and Lee marked the greatest advance in physical thought since the birth of quantum mechanics in 1926. I held a watching brief as a representative of our unborn Institute and I returned from Princeton with no other thought dominating my mind except to reproduce, in a small measure at least, the atmosphere for such creative work. Chance and circumstance came to my favour when a small band of students, stricken by the same splendid sickness, gathered round me in goodly friendship. We had no resource at our command except the love of common excitement for doing something new. To this fraternity we gave the name - "Theoretical Physics Seminar". It was located in my family home with the consent of my gracious wife. We met in leisured comfort and indulged in the impertinence of attempting to work on the same type of problems as are engaging the attention of theoretical physicists elsewhere. We were encouraged in our efforts by the frequent visits of famous physicists whose friendliness and cooperation were our only sources of strength and sustenance. What a fine hour it was when Bohr and Salam who span the growth of modern physics from atomic physics to guage theories of elementary particles, evinced an interest which gave us the strength to hope when we were all alone and everything seemed so near despair. We waited and watched for something to happen.

It was one of the fortunate moments of my life when I met the Finance Minister one evening at a gathering of international students. It puzzled me beyond comprehension to find the Minister, who must be more concerned with building dams and bridges, getting interested in the development of mathematical research. I felt a trifle guilty that I had inveigled him into this domain which had intoxicated me and my associates beyond reason. Soon I realised that it became almost a faith with him, a faith which was strengthened by his recent visit to the United States. He returned with the conviction that creative science needed the noble heat of youthful ambition and not the tepid caution of unfeeling mediocrity. Before proceeding to take steps for the creation of an institute for advanced learning, he was anxious to have the blessings and active support of our Prime Minister. It occured to him in a discussion with my esteemed and genial friend Dr. M. M. Shapiro that all students associated with me should be introduced to the Prime Minister during

his visit to Madras. The impression they made on our Prime Minister was more due to his generosity than to their own achievements. It was his wide humanity and deep concern for the prosperity of our country that made him see the light of hope even in the feeble efforts of smaller men. His support by agreeing to be our Patron, gave that final impulse which resulted in the setting up of this Institute.

The final act in this strange dream is even more fantastic than the events that preceded it. I approached Professor S. Chandrasekhar, one of the greatest astrophysicists of our time, who stands so high above the rest of our own common mould, with a request that he should associate himself with the new Institute. It was an insolence on my part to do so when I was assuming the Directorship of the Institute. I suppose you will excuse me for this if I assure you that the spirit in which I did so was animated by that in the greatest of legends when Arjuna approached Lord Krishna for his support. It was accepted with that same legendary grace, and the Institute has honoured itself by his association with it. This band of students, this firstlings of the fold, must consider themselves to be the happy few to have chosen him as their guide.

This then is the genesis of this new Institute which symbolises the hopes and ideals of the entire scientific community in India. The Government of Madras and in particular the Chief and Finance Ministers ably assisted by the Education Secretary, another victim of the splendid sickness, must be congratulated for the most gracious gesture that has ever been made by any administrative authority to the academic community in our country. The best tribute we can pay to our government is to say, "it does not seem to be the red tape - it is the blue riband." Is it not natural that greetings have poured from scientists all over the world, from California in the west to Sydney in the east? To those scientists who visited Madras, whose very presence had introduced the heady atmosphere of Berkeley into the placid environs of my family home, we are deeply grateful, for they kept alive the state of hope till the moment of its realisation. As for myself, it is a period of thanksgiving to my great teachers Professor Bhabha and Professor Bartlett who initiated me into theoretical physics. My only regret is that my parents whose home nursed the happy breed, are not alive today at the crucial moment of my academic life. In recompense I shall pass on to my students their message that the pursuit of science is at its best when it is a part of a way of life. That is the ideal to which this institute is dedicated.

LIST OF PUBLICATIONS OF ALLADI RAMAKRISHNAN INCLUDING THOSE WITH THE SEMINAR STUDENTS, 1947-1965

I provide here the list of papers published by my father until the year of the creation of MATSCIENCE and including the papers he published with the students of the Theoretical Physics Seminar till they completed their PhD.

1) (with H. J. Bhabha) "The mean-square deviation of the number of electrons and quanta in cascade theory", *Proc. Indian Acad. Sci.* **32** (1950), 141-153.

2) "Stochastic processes relating to particles distributed in a continuous infinity of states", *Proc. Cambridge Phil Soc.*, **46** (1950), 595-602.

3) "A note on the size frequency distribution of penetrating showers", *Proc. Phys. Soc. London*, **63A** (1950), 861-863.

4) "Stochastic processes and their applications to physical problems" *PhD Thesis, Univ. Manchester* (1951).

5) "Some simple stochastic processes", *J. Royal Stat. Soc.*, **13** (1951), 131-140.

6) "A note on Janossy's mathematical model of a nucleon cascade", *Proc. Cambridge Phil. Soc.*, **48** (1952), 451-456.

7) "On an integral equation of Chandrasekhar and Munsch", *Astrophysical J.*, **115** (1952), 141-144.

8) "Stochastic processes associated with random divisions of a line", *Proc. Cambridge Phil. Soc.*, **49** (1953), 473-485.

9) (with P. M. Mathews) "A stochastic problem relating to counters", *Phil. Mag.*, **44** (1953), 1122-1127.

10) (with P. M. Mathews) "Numerical work on the fluctuation problem of electron cascades", *Prog. Theor. Phys.* **9** (1953), 679-681.

11) (with P. M. Mathews) "On a class of stochastic integro-differential equations", *Proc. Indian Acad. Sci,* Ser A **38** (1953), 450-466.

12) (with P. M. Mathews) "On the solution of an integral equation of Chandrasekhar and Munsch", *Astrophysical J.*. **119** (1954), 81-90.

13) "A stochastic model of a fluctuating density field", *Astrophysical J.*, **119** (1954), 443-455.

14) "A stochastic model of a fluctuating density field - II" *Astrophysical J.*, **119** (1954), 682-685.

15) "On the molecular distribution functions of a one dimensional fluid - I", *Phil. Mag.*, **45** (1954), 401-410.

16) "On counters with random dead time" *Phil. Mag.*, **45** (1954), 1050-1052.

17) (with P. M. Mathews) "On the molecular distribution functions of a one dimensional fluid - II", *Phil. Mag.*, **45** (1954), 1053-1058.

18) (with P. M. Mathews) "Studies in the stochastic problem of electron-photon cascades", *Prog. in Theor. Phys.*, **11** (1954), 95-117.

19) (with S. K. Srinivasan) "Two simple stochastic models of cascade multiplication", *Prog. in Theor. Phys.*, **11** (1954), 595-603.

20) "On stellar statistics" *Astrophysical J.*, **122** (1955), 24-31.

21) "Inverse probability and evolutionary Markov stochastic processes", *Proc. Indian Acad. Sci.*, **41** (1955), 145-153. (Read at the Annual Meeting of the Academy in Belgaum, Dec 1954.)

22) (with S. K. Srinivasan) "Fluctuations in the number of photons in an electron-photon cascade", *Prog. in Theor. Phys.*, **13** (1955), 93-99.

23) (with P. M. Mathews) "Straggling of the range of fast particles as a stochastic process", *Proc. Indian Acad. Sci.*, **41** (1955), 202-209. (Read at the Annual Meeting of the Academy in Belgaum, Dec 1954.)

24) "Phenomenological interpretation of the integrals of a class of random functions", *Proc. Koninkl. Netherlands Akad.* **58** (=*Indag. Math.*, **17**) (1955), 470-482.

25) "Phenomenological interpretation of the integrals of a class of random functions - II", *Proc. Koninkl. Netherlands Akad.* **58** (=*Indag. Math.*, **17**) (1955), 634-645.

26) (with S. K. Srinivasan) "Correlation problems in the study of brightness of the Milky Way", *Astrophysical J.*, **123** (1956), 479-485.

27) "Processes represented as integrals of a class of random functions", *Proc. Koninkl. Netherlands Akad.* **59** (=*Indag. Math.*, **18**) (1956), 121-127.

28) (with P. M. Mathews) "Stochastic processes associated with a symmetric oscillatory Poisson process", *Proc. Indian Acad. Sci.*, **43A** (1956), 84-98.

28) (with S. K. Srinivasan) "A new approach to cascade theory", *Proc. Indian Acad. Sci.*, Ser. A. **44** (1956), 263-273.

30) "A physical approach to stochastic processes", *Proc. Indian Acad. Sci.* Ser A, **44** (1956), 428-450.

31) (with S. K. Srinivasan) "Stochastic integrals associated with point processes" (in French), *Publ. Inst. Stat. Univ. Paris*, **5** (1956), 95-106.

32) (with R. Vasudevan) "On the distribution of visible stars", *Astrophysical J.*, **126** (1957), 573-578.

33) "Ergodic properties of some simple stochastic processes", *Z. angew. Math. Mech.*, **37** (1957), 336-344. (Read at the GAMM Conference in May 1956 in Stuttgart.)

34) (with S. K. Srinivasan) "A note on cascade theory with ionisation loss", *Proc. Indian Acad. Sci.*, Ser. A **45**(1957), 133-138.

35) (with N. R. Ranganathan, S. K. Srinivasan and R. Vasudevan) "Multiple processes in electron-photon cascades", *Proc. Indian Acad. Sci.*, Ser. A, **45**(1957), 311-326.

36) (with S. K. Srinivasan) "On age distribution in population growth", *Bull. Math. Biophys.*, **20** (1958), 289-303.

37) "Theoretical physics in the USA", *Current Sci.* **27** (1958), 469-471.

38) "Ambigenous stochastic processes", *Z. angew Math. Mech*, **39** (1959), 389-390.

39) (with N. R. Ranganathan and S. K. Srinivasan) "Meson production in nucleon-nucleon collisions", *Nucl. Phys.*, **10** (1959), 160-165.

40) (with N. R. Ranganathan, S. K. Srinivasan and K. Venkatesan) "Photo-mesons from polarized nucleons" *Proc. Indian Acad. Sci. Ser. A***49** (1959), 302-306.

41) (with N. R. Ranganathan and S. K. Srinivasan) "A note on the interaction between nucleon and anti-nucleon", *Proc. Indian Acad. Sci.*, **50** (1959), 91-94.

42) "Probability and stochastic processes" in *Handbuch der Physik* (S. Flugge, Ed) **III/2** (1959), Springer-Verlag, Berlin (1959), 524-651.

43) (with N. R. Ranganathan, S. K. Srinivasan, and R. Vasudevan) "A note on dispersion relations", *Nuclear Phys.*, **15** (1960), 516-518.

44) "Perturbation expansions and kernel functions associated with single particle wave functions" in *Studies in Theor. Phys., Proc. 1959 Mussoorie Summer School* **1** (1960), 1-14.

45)"Quantum mechanics of the photon" in *Studies in Theor. Phys., Proc. 1959 Mussoorie Summer School* **1** (1960), 15-18.

46) "Applications of the theory of stochastic processes to physical problems", in *Studies in Theor. Phys., Proc. 1959 Mussoorie Summer School* **2** (1960), 239-253.

47) (with R. Vasudevan) "A physical approach to some limiting stochastic operation", *J. Indian Math. Soc.* **XXIV** (Golden Jubilee Volume, 1960), 458-477. (work done at Institute for Advanced Study in 1957-58; paper read by AR at Int'l Congress of Math., Edinburgh, 1958)

48) (with A. P. Balachandran and N. R. Ranganathan) "Some remarks on the structure of elementary particle interactions", *Proc. Indian Acad. Sci.*, **52** (1960), 1-11.

49) (with T. K. Radha and R. Thunga) "On the decomposition of the Feynman propagator" *Proc. Indian Acad. Sci.*, Ser. A, **52** (1960), 228-239.

50) (with P. Rajagopal and R. Vasudevan) "Ambigenous stochastic processes", *J. Math. Analysis and Appl.*, **1** (1960), 145-162. (Read by AR at the GAMM Conf., Hanover in May 1959)

51) (with. T. K. Radha) "Correlation problems in evolutionary stochastic processes", *Proc. Cambridge Phil. Soc.*, **57** (1961), 843-847.

52) (with A. P. Balachandran, N. G. Deshpande, and N. R. Ranganathan) "On an isobaric spin scheme for leptons and leptonic decays of strange particles", *Nucl. Phys.*, **26** (1961), 52-56.

53) (with R. Vasudevan) "A physical approach to limiting stochastic operations", *J. Indian Math. Soc. (N.S)* **24** (1961), 457-477.

54) (with G. Bhamathi and S. Indumathi) "A limiting process in quantum electrodynamics", *Proc. Indian Acad. Sci. Ser A*, **53** (1961), 206-213.

55) (with V. Devanathan and G. Ramachandran) "A time dependent approach to rearrangement collosions", *Il Nuovo Cimento*, **21** (1961), 145-154.

56) (with S. K. Srinivasan) "A note on electron photon showers", *Nucl. Phys.*, **25** 1961), 152-154.

57) (with G. Bhamathi, S. Indumathi, T. K. Radha, and R. Thunga) "Some consequences of spin $\frac{3}{2}$ for Ξ", *Il Nuovo Cimento*, **22** (1961), 604-609.

58) (with V. Devanathan and G. Ramachandran) "Elastic photo production of nuetral pions from dueterium", *Nucl. Phys.*, **24** (1961), 163-168.

59) (with N. R. Ranganathan) "Stochastic models in quantum mechanics" *J. Math. Analysis and Appl.*, **3** (1961), 261-294. (Presented by AR at the Conference on Elementary Particles, Trieste 1960)

60) (with K. Venkatesan) "Some new stochastic aspects in cascade theory", *in Proc. 7-th Annual Cosmic Ray Symposium, Chandigarh* (1961), 59-61.

61) (with T. K. Radha) "Essay on symmetries" *Lectures at the Kodaikanal Summer School*, **2** (1961), 1-77.

62) (with N. R. Ranganathan) "Stochastic methods in quantum mechanics", *J. Math. Analysis and Appl.*, **3** (1961), 261-294.

63) (with T. K. Radha and R. Thunga) "The physical basis of quantum field theory", *J. Math. Analysis and Appl.*, **4** (1962), 494-526.

64) (with T. K. Radha and R. Thunga) "On the concept of virtual states", *J. Math. Analysis and Appl.*, **5** (1962), 225-236.

65) (with G. Ramachandran) "Magnetic bremsstrahlung in nucleon-electron collisions", *Rand Corporation Preprint*, Los Angeles (1962).

66) "New perspectives on the Dirac Hamiltonian and the Feynman propagator", *in High Energy Phys. and Fundamental Particles*, Gordon and Breach, NY (1962), 665-672.

67) (with A. P. Balachandran and K. Raman) "Low energy K^+-nucleon scattering", *Il Nuovo Cimento*, **24** (1962), 369-378.

68) (with V. Devanathan and K. Venkatesan) "On the scattering of pions by dueterons", *Nucl. Phys.*, **29** (1962), 680-686.

69) (with T. K. Radha and R. Thunga) "Possible resonances in Ξ_p reactions", *Nucl. Phys.*, **29** (1962), 517-523.

70) (with A. P. Balachandran) "Partial wave dispersion relations for Λ-nucleon scattering", *Il Nuovo Cimento*, **24** (1962), 980-999.

71) (with A. P. Balachandran, T. K. Radha, and R. Thunga) "On the Y^* resonances", *Il Nuovo Cimento*, **24** (1962), 1006-1012.

72) (with A. P. Balachandran, T. K. Radha, and R. Thunga) "On the spin and parity of Y^* resonances", *Il Nuovo Cimento*, **25** (1962), 723-729.

73) (with A. P. Balachandran, T. K. Radha, and R. Thunga) "Photo production of pions and Λ-hyperons", *Il Nuovo Cimento*, **25** (1962), 939-942.

74) (with G. Bhamathi, S. Indumathi, T. K. Radha, and R. Thunga) "Dispersion analysis of Ξ production in KN collisions" *Nucl. Phys.*, **37** (1962), 585-593.

75) (with T. K. Radha, K. Raman, and R. Thunga) "Quantum numbers and decay models of resonances" *Rand Corp. Preprint*, Los Angeles (1962)

76) "An unconventional view of perturbation expansions", *in Proc. Seminar on Unified Theories of Elem. Particles, Univ. Rochester, D. Lurie and N. Mukunda, Eds.* (1963), 411-421.

77) (with V. Devanathan and K. Venkatesan) "A note on the use of Wick's theorem", *J. Math. Analysis and Appl.*, **8** (1964), 345-349.

78) (with K. Raman and R. K. Umerjee) "Isobar production in nucleon-nucleon scattering", *Nuclear Phys.*, **60** (1964), 401-426.

79) (with K. Raman and R. K. Umerjee) "Isobar production in nucleon-nucleon scattering - II, Polarization effects", *Nuclear Phys.*, **66** (1965), 609-631.