80th birthday celebrations of S. Naranan on 5 Dec 2010

Talk by S. Naranan

In my B.Sc. equal weightage was given to all the three subjects Mathematics, Physics and Chemistry. This gave me a choice of any of the three subjects for M.Sc. I loved all the subjects, thanks to the inspiring teachers I had. But my favourite subject was Mathematics, perhaps because it was taught by my father. However I chose Physics because it offered better career opportunities in the late 1940's. I was admitted to the Benares Hindu University (M.Sc. Physics) in 1948. At the time of admission I was shocked to learn that my admission had been cancelled because I had not paid the fees in advance. Fortunately I had the acknowledgment from BHU of my Money Order for the fees I had sent. With this, I met the Head of the Physics Department and told him my predicament. The professor looked at my marks – I was first rank in B.Sc – and instantly gave me admission, creating an extra seat increasing the class strength from 12 to 13. He added that I deserved admission more than anybody else. But for his generosity, I would have probably become a chemist instead of a physicist. The name of the professor is Dasannacharya whose son (Anant) became a close family friend of A.R.Sundaresan family nearly a decade later.

M.Sc. was a memorable educational experience. The physics lab was excellent and we did many classic experiments in the first year. For the second year, half the time was devoted to a thesis. I did Spectroscopy under Prof. R.K. Asundi, a brilliant experimental physicist. (It is said that he was an expert glass blower and learnt glass blowing so that he could make tubes with very thin walls that would allow some ultraviolet radiation to pass through. He could not afford quartz tubes for ultraviolet spectroscopy). I loved doing experiments. Once I was asked to measure wavelengths of spectral lines on a plate. For one line, I got a value, which differed from the value written on the plate in the first decimal place. The error was only one part in 10,000. However I checked and rechecked and got the same answer. When I mentioned the discrepancy to my Professor, he checked my value with the standard wavelength tables and found that my value was in exact agreement! He remarked, “Naranan, you should get a Nobel prize”. It was not mockery but an exaggerated compliment. I realised this after I got to know him better.

I hated writing exams and the last day of my M.Sc. exams was a very happy day, because that was the last exam in my life. But I was a good student and generally scored high marks. I had highest marks in B.Sc and M.Sc (81 %) getting the top rank in both. In B.Sc. Chemistry I had 81 %, again the highest. I never got 100 % in Maths in any exam. My M.Sc. thesis marks 196/200 was a record in 1950; it remains a record because BHU discontinued M.Sc by thesis from the following year.

Here is an interesting episode about my M.Sc. marks. I was in Berhampur with my parents when I received the telegram from a friend in BHU, giving my aggregate marks as 81 %. A classmate in M.Sc. who also lived in Berhampur had a telegram from the same friend, giving her marks as 81 %. So it appeared to be a tie, but it turned out that my telegram was mistakenly repeated to her too by the BHU post office.

In class exams at college in Berhampur, I rarely missed 100 % in Maths. Often I got 105 % or 110 % because of my father’s unconventional marking scheme. He would give bonus marks if one problem were solved by two different methods. In class he would often give alternate methods of solution for the same problem. In one Intermediate class test I got 60 % in English. The first marking of the examiner gave a total of 61 %. One answer was marked down by one mark to bring the total to 60 %. When asked, the examiner said ‘nobody gets more than

60 % in English'. In high school, in Form IV, I failed in the History exam. My first day at school was in Std V at age 8. I had an arithmetic test the same day. My score was zero. Questions were all on 'place value' up to 10 digits. My tuition teacher had taught me only place values up to five digits.

After my M. Sc., I had to resist some pressure to write the IAS exams for Central Government Service. But I had decided on a research career in Physics, although it meant a career far less glamorous than that of a District Collector or an Officer in the Indian Foreign Service. My parents fully endorsed my decision.

Cosmic Rays are high-energy particles, consisting of nuclei of all atoms such as hydrogen, helium, carbon, nitrogen, oxygen etc. with hydrogen accounting for 90 % of the total. They impinge on earth from outer space. Victor Hess discovered Cosmic Rays by chance in 1911. He found that the electric charge stored in his electroscope was leaking. He guessed that it was due to the radioactivity from earth, which ionises the air surrounding his apparatus. To confirm this, he took his electroscope in a balloon flight, hoping to find that the effect of radioactivity will disappear as the balloon soared to greater heights. However the ambient radiation increased rather than decrease at greater heights. He concluded that the radiation came from outer space and not from the earth. Next year will be the centenary of the discovery of Cosmic Rays; yet we don't understand well the precise source of their origin in the universe.

In M.Sc. I had won a prize – a book of my choice – for an essay on Cosmic Radiation. Dr. H.J.Bhabha had chosen Cosmic Rays as the main field of experimental research at the Tata Institute of Fundamental Research (TIFR) Bombay, because Cosmic Rays are high-energy nuclear particles, a powerful tool for research in High Energy Nuclear Physics. Such high energies could not be produced in the laboratory. So Cosmic Ray research was exploring the unknown. So, it was a natural choice for me when I joined TIFR

I worked in the TIFR (Bombay, now Mumbai) for 42 years from 1950-92. The first half of my research career was devoted to Cosmic Rays (experimental). Research in Cosmic Rays was truly an adventure, working deep underground in Kolar Gold Fields, under water in Sathanur dam and in an abandoned Railway tunnel in Khandala, near Pune. The depths of our experiments at KGF ranged up to 3 Km (10,000 ft) even greater than the altitude of Ooty (2.2 Km, 7200 ft). For several years my research work shifted from KGF to Ooty (1954-1961). B.V. Sreekantan and I started the KGF experiments in 1951. I was the last candidate for Ph.D registered with Dr. Bhabha as my guide.

At KGF we studied the elementary called 'mu meson' or 'muon'. In the scheme of Nature's fundamental particles, muon was a misfit; the joke was "who ordered the muon?" Now we know that muon is nothing but a heavy electron. It behaves like an electron but is about 200 times heavier and is short lived with an average lifetime of about two millionths of a second. We did a cloud chamber experiment housed in a specially built mobile laboratory that was driven from Bombay to an abandoned railway tunnel in Khandala, near Pune. Muons had to penetrate about 300 ft. of rock before entering the cloud chamber. From a detailed study of these muons interacting with matter, we were able to conclude that the muon indeed behaved like a heavy electron. At that time the nature of muon was still controversial. This important result was the basis of my Ph.D thesis. Mr. A.B. Sahiar, a senior scientist conceived and built the mobile laboratory. I owe a lot indeed to his vision, engineering skill and enthusiasm for the successful expedition. Dr. Bhabha had indeed suggested earlier – as far back as 1937 – that muon's behaviour was consistent with being a heavy electron.

Now, I would like to divert to an interesting observation I made in KGF. We had measured the number of muons penetrating four depths: approximately 200 ft, 400 ft, 600 ft and 1000 ft. in the Bullen Shaft in 1951. Comparing our numbers with some earlier experiments (done under water) it appeared that we were finding more muons than in the earlier experiments. The discrepancy was maximum at 200 ft and progressively less at deeper levels. Temptation was to take the discrepancy as real. After many checks and rechecks of our results I thought I should check out the depths (200 ft. etc) though there was no reason to doubt the accuracy of the KGF survey maps. At the survey office, first they confirmed the depths as correct. Then I noticed that the depths given were vertical depths below "field datum". The KGF is undulating and the surveyors had chosen an average surface level, the field datum as a reference for measuring depths. But what we needed were depths below the surface of Bullen Shaft. It turned out that the Bullen Shaft surface was about 100 ft. below the field datum. So we had to subtract 100 ft. from all our depths. The new depths were 100, 300, 500 and 900 ft. With this correction there was perfect agreement with earlier work. This almost trivial discovery was however exciting, because it meant that the observed number of muons at an unknown depth can be used to find the depth!

Nearly 16 years later (c 1967) the same idea was used by the reputed physicist Alvarez to find any hidden chambers in one of the famous pyramids in Egypt. He set up muon detectors around the pyramid and counted the muons arriving from different directions. Then he calculated the amount of matter they had crossed before entering the detectors. He constructed a crude 3-dimensional model of the pyramid. In modern terminology this can be called muon tomography. I think the results were inconclusive about the existence or otherwise of empty chambers.

During the KGF phase of my research, I got married to Visalam on 24 May 1953, a very memorable day of my life. I was only 23 years old. Her father A.R. Sundaresan took the trouble of coming to KGF with a mutual friend, to see me. He spent only a few hours with me. I recall an interesting incident soon after my marriage. I had written a long, 8-page letter to my father while on night shift at our KGF laboratory underground. Next morning, I requested my colleague Ramanamurthy to post the letter. Later, Ramanamurthy told me that he went to the post office but did not remember posting my letter. He added that he probably lost my letter on his way to the post office. Two days later I rewrote my letter, with the same contents, and posted it. After a few days my father wrote that he received two nearly identical letters from me two days apart. My mother, in particular wondered if my underground work was affecting my mental state. But it was clear that I was mentally sound; otherwise I could not have repeated the first letter almost verbatim.

My eldest daughter Vidya was born in Bombay in December 1954 when I was in Ooty. At Ooty we first worked with cloud chambers. Cloud chambers are “magical devices” which help visualize Cosmic Ray particles and their interactions with matter. Later we moved on to study Cosmic Rays of extremely high energy, a million times more energetic than particles that could be produced in particle accelerators anywhere in the world. These experiments were very elaborate with many large area particle detectors (scintillators) and very sophisticated state-of-the-art electronics. These experiments are called “Extensive Air Shower” (EAS) experiments. In 1961 I returned to KGF to merge the two areas of research: EAS and high-energy muons.

The second phase of my research career started in 1967 in X-ray Astronomy. There is continuity in the first and second phases: Cosmic Rays are High Energy Particles whereas X-rays are High Energy Electromagnetic Radiation from outer space. The electromagnetic spectrum – from radio waves to ultra-high energy gamma rays - spans over 25 decades of energy scale (factor 10^{25}).

X-ray Astronomy had burgeoned as a new discipline only in early 1960's and the pioneers in the field were Cosmic Ray physicists. I worked at M.I.T (Cambridge, USA) from 1967-69 on the first rocket-borne experiment of M.I.T, which led to the discovery of several new bright X-ray sources. Then I worked for one year on the first X-ray satellite ever flown – called the UHURU – before its launch by the American Science & Engineering (AS&E) headed by Dr. R. Giacconi. Dr. Giacconi was a pioneer and was awarded the Nobel Prize in 2002. MIT and AS&E had jointly flown the first rocket-borne experiment with X-ray detectors in 1962 that heralded the birth of X-ray Astronomy with the discovery of Sco X-1, the non-solar X-ray source in the Universe.

At TIFR, rocket X-ray Astronomy program was started in 1970. Rockets were launched from Thumba (near Trivandrum) and then from Sriharikota (Andhra Pradesh). Balloon-borne experiments in X-ray Astronomy (for energetic X-rays) had begun even earlier. They were launched from the TIFR Balloon Launching Facility at Hyderabad. The facility over the decades has grown into a major world-class facility for balloon experiments.

It is necessary to elaborate on the scale of these experiments because the term 'balloon' conjures up in mind toy balloons or hot-air balloons in sport. In scientific ballooning the size of the balloon is about 300 to 500 ft in diameter at a height of 40 Km. Its volume is 10 to 20 million cubic feet. On the ground about 5 % of this volume is filled with hydrogen gas from hundreds of commercial cylinders. It is tethered to the experimental payload that weighs up to a ton. The balloon drifts at a constant height of about 40 Km for several hours or more depending on the wind. When the experiment is over the balloon is separated by radio control, from the payload. A parachute brings the payload to land safely. It is collected usually from a remote field or village. The balloon is tracked throughout by radar or GPS. The National Balloon Facility in Hyderabad has the start-to-end capability: manufacturing of gigantic polyethylene balloons, launching them, tracking them and recovering the payload.

For a few years before my retirement from TIFR I was working on the first X-ray satellite experiments from India. The satellites were launched after my retirement in 1992.

Briefly the following are some impressions about launches of vehicles. Least impressive is the satellite launch. The booster carrying the satellite is huge but starts lifting off from the launch pad very slowly. But watching a rocket launch is a magical experience. The rocket on the launch pad disappears in a split second, the wink of an eye. You see it now and then next moment it is gone as in a vanishing trick. Most exciting is the balloon launch: guiding the balloon to a vertical position, filling it with hydrogen gas and letting it take off gently when the ambient wind is low. Watching it, tracking it and recovering the payload are a rewarding experience I will always remember.

During the years 1967-1990, I spent nearly seven years in total at seven research institutions in the forefront of X-ray Astronomy research, in Boston, Washington D.C and Huntsville (AL) in U.S.A and in Munich, Germany. I visited Calgary (Canada) several times because of collaboration between TIFR and Prof. D. Venkatesan (University of Calgary).

Now, I will refer briefly to areas of my research outside Physics and Astronomy starting from 1960's. My main interests were in Mathematics (Statistics, Number Theory and Recreational Mathematics). Since Mathematics is a universal tool for research I was led to other areas like Computation, Cryptography (secret communication), Complexity and Chaos theory, Information Theory, Statistical Linguistics (including some work on Indus texts), DNA sequences (language of life) and Evolutionary Genetics. Somewhat distinct from the above are Interpretation of Dreams, Bibliometrics (science of science) Kolam

Art and Crossword puzzles. Sometimes a hobby leads to a scientific publication too. A few concrete examples follow.

(1) This is a popular tale in folklore. Three men came to Akbar's court seeking a solution to the problem of sharing a property willed by their father. Father had willed that one-half of his property should go to the eldest son, one-third to the next and one-ninth to the youngest. The property consisted of 17 elephants. Being a prime number, 17 cannot be divided by 2,3 or 9. Birbal the legendary courtier had the following solution. He added the Royal Elephant to the group making the number 18. Then the sons took 9,6 and 2 elephants leaving behind the Royal elephant. At first this looks mysterious, but the reason it works is simple. A half, a third and a ninth add up to 17/18 and not 1.

I considered the following generalizations. (1) Are there any other triples, other than (2,3,9) for which a similar relation holds? (2) Are there other multiple sets with more than 3 partitions that behave in a similar way? (3) If so is there a systematic way to find the sets? The answer is yes for all the three questions. I wrote a short paper that was published in Mathematics Magazine.

(2) The second problem is construction of any desired angle using only the ruler and compass. The ruler is used only to join two points and the compass is used for drawing arcs or circles. According to Number Theory there is only a set of angles that can be so constructed. For example it is easy to construct angles 90, 60, 45 and 30 degrees. 72^{o} is more complex but can be done. Less known is the fact that 21.17..degrees (360/17) can also be constructed. Gauss was very proud of this discovery.

I found out that any desired angle could indeed be constructed by ruler and compass **to any desired finite degree of accuracy** – for example 38.254 degrees. This does not contradict theory because one is not asking for infinite precision. I was very excited about this discovery. It was published in Mathematical Gazette.

(3) I have been solving cryptic crossword puzzles regularly for over 40 years. Many consider they are a waste of time. But I think they are entertaining and good exercise for the brain. Indeed they are recommended pursuit to ward off dementia. About 20 years ago I started keeping a record of the number of unsolved clues (failures) for each puzzle. I began to see a pattern in these numbers and was able to find a statistical distribution function that fits them. Ten years of data (3404 puzzles) was used to firm up my earlier conclusions. The distribution is the Negative Binomial Distribution (NBD), which is ubiquitous in many branches of science. For example NBD is used in car insurance industry to fix insurance rates based on accident statistics. It was exciting to realize that crossword puzzle error statistics can be modeled like car accidents. This was the longest duration experiment I have ever done (10 years). I found great satisfaction in writing up this research as a paper for publication in the Journal of Quantitative Linguistics. More satisfying is the fact that the Editor accepted it for publication with no changes within a few days of its submission. The paper appeared in August this year. Perhaps this is the most unusual instance of a hobby becoming a basis for a scientific publication.

(4) From a very young age I had a fascination for *kolam* designs, the South Indian folk art. *Kolams* are drawn around a grid of points. In 2007, I found a beautiful mathematical link between Fibonacci numbers (1 1 2 3 5 8 13 21 ...) and *kolam* designs. This connection could be exploited to produce *kolams* of any arbitrary size and shape using smaller modules. The recursive process made the *kolams* amenable to computer-aided design, for creating intricate and complex patterns. I had written a long article on the subject. It is not published but is accessible on my website. The reason I mention it here, with some pride, is the appreciation it received from Martin Gardner, a celebrated leading exponent of Recreational Mathematics. Gardner read my long paper and replied to me within

24 hours of his receiving it (22-4-2010). His letter reveals that he was in poor health. He died exactly a month later at age 95. Gardner is best known for his articles on Recreational Mathematics in Scientific American for 25 years (1957-82). Each of the 300 articles is considered a classic and is reprinted with updates and addenda many times. Gardner wrote in his letter

> *"Thanks for sending me those beautiful papers. If I were still with Scientific American, I would be devoting one of my columns to them...."*

I consider this is the greatest appreciation my *kolam* work can receive.

With this I conclude my rather long talk. I am very grateful to all of you for your patience in listening to me and for attending this function. Some of you have traveled long distances specially to be here and they deserve my special thanks. I thank all those who were responsible for organizing this function; especially my daughter Venil Sumantran and Bhama who took care of numerous details that needed to be tackled.

Chennai, 5-12-2010 S. Naranan