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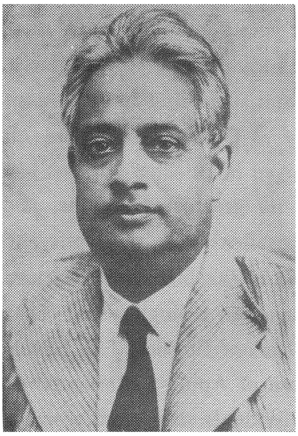
S.N. BOSE (1894-1974) AND THE BOSE QUANTUM STATISTICS A CENTENNIAL TRIBUTE



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ABSTRACT. This centennial tribute commemorates Bose the Man and Bose the Scientist. A survey of S.N. Bose's life and career is presented in some detail. His major scientific contributions including the discovery of Bose statistics and the novel derivation of the Planck black body radiation formula are described.

KEY WORDS AND PHRASES. Bose (Bose-Einstein) statistics, quantum statistics, Planck radiation formula, photons, Fermi-Dirac statistics, Bosons, and Fermions.
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1. THE LIFE AND CAREER.

The old city of Calcutta has at least five claims to fame. It was the capital of India; and has the unique tradition of being the artistic and intellectual capital of the subcontinent. All three Indian Nobel Prize winners have come from this city. They were Rabindranath Tagore (Nobel Prize for Literature in 1913), C.V. Raman (Nobel Prize for Physics in 1930) and Mother Theresa (Nobel Peace Prize winner in 1979). During the first quarter of the century, this city has been associated with three notable scientific discoveries including Saha's Theory of Thermal Ionization of Stars, Bose-Statistics and Raman Effect. Calcutta used to serve as India's chief port for trade with southeast Asia; and more importantly, it is the birthplace of Satyendra Nath Bose. The last event took place on January 1, 1894, in a middle class Hindu family of the State of Bengal. Bose's mother, Amodini Devi was the daughter of an established lawyer of Calcutta and his father, Surendra Nath Bose was an accountant and, later in his life, held a responsible position at the Executive Engineering Department of East Indian Railways.

Bose spent early school years in the famous Hindu School in Calcutta, where he came in contact with formidable rivals in his class, and fine teachers who quickly recognized his tremendous mathematical ability. His mathematics teacher predicted that Bose would one day become a great mathematician like Euler or Laplace. Love for mathematics dominated Bose's career in his advanced study and research. After attending high school, Bose entered Calcutta Presidency College in 1909 to pursue a Bachelor of Science degree with Mathematics Honors, Physics and Chemistry as minor subjects. At Presidency College, he received special attention by his professors for his remarkable ability and performance in all subjects. Bose's abilities in English language matched those in mathematics, and later on he learned several other languages including German, French and Italian. Among his friends and talented classmates at Presidency College were M.N. Saha, J.C. Ghosh and J.N. Mukherjee. All these young individuals including Bose had a common goal and spirit of patriotism originated from the Indian Freedom Movement. Bose successfully graduated from the University of Calcutta in 1913 and stood first in rank in his Bachelor of Science. In the same year, he entered the University of Calcutta to pursue his Master of Science degree in mixed mathematics. In 1915, Bose received his master's degree just when the Bohr theory of atomic structure had started enjoying its greatest triumphs, and physicists of the western world were trying to apply this theory to all aspects of atomic and nuclear physics. There is no doubt that 1915 was a remarkable year in the history of Calcutta University in the sense that so many eminent scientists were produced in a single year. They included S.N. Bose, M.N. Saha, S. Dutta, A. Chakraborty and S. Ghosh of Physics, J.C. Ghosh, J.N. Mukherjee, P.K. Bose, and P.B. Sarkar of Chemistry, N.R. Sen of Applied Mathematics, S.C. Dhar of Pure Mathematics, and P. Parija of Botany. These individuals started off research in their respective fields at the University of Calcutta, and subsequently received recognition for their original research contributions. In 1917, post-graduate programs in applied mathematics and in physics were created, and the department of chemistry was reorganized. In the same year, S.N. Bose and M.N. Saha were appointed lecturers in physics, both of them later on became the Fellow of the Royal Society of London in recognition of their fundamental contributions to physics.

In 1914, at the age of twenty, Bose was married to Ushabala Ghosh, the only child of Jogindra Nath Ghosh, a successful medical doctor of North Calcutta. There were seven children of the marriage, two sons and five daughters. With the help of his devoted wife, Bose raised his children with loving care and affection. In spite of his big family, his personal life was simple and peaceful. Bose has a natural love not only for mathematics and science, but also for his motherland and her people. He loved cats, classical music and modern literature. In his leisure time, Bose used to play the Esraj (an Indian stringed musical instrument) and flute. In addition, he had taken keen interest in Bengali literature throughout his life. His feelings and faith on human beings in general and young people in particular were strong and deep. He felt a deep affinity with the ideas of Pierre Teilhard de Chardin and wrote an article on him in Bengali in which Bose had drawn the attention to his own countrymen to the extraordinary self-sacrifice and love of humanity of Pierre Teilhard: "We have to overcome heroically all obstacles and impediment to build future civilisations, irrespective of all religious and national differences. The whole humanity will be included in it. This is the message of hope we learn from science. A scientific attitude to life, cooperation and love in place of envy and jealousy, that is what we need, and the history of evolution shows the way to this end. Victory will come through science. By refusing the aid of science man can never attain the ultimate aim of life".

A new chapter in Bose's life and career had begun in 1917 with his first teaching and research position at the Physics Department of the University of Calcutta. At the same time, he was greatly influenced by the new physics that begun with the revolutionary formulation of Max Planck's quantum hypothesis for the derivation of the energy distribution of the black body radiation and Einstein's discovery of equivalence of mass and energy. Based upon the electromagnetic theory of classical statistical mechanics, Planck formulated his famous law,

$E = h\nu$ for the energy E of the quantum with frequency ν, where h is the so called Planck constant. Einstein conclusively proved the equivalence of mass and energy with the derivation of his 1907 famous equation, $E = Mc^2$. These new and revolutionary developments in physical sciences were more or less unknown to Indian students or scholars mainly due to lack of original scientific literature written mostly in German. In 1917, C.V. Raman was appointed to the newly established Palit Professor of Physics at the University of Calcutta. By 1924, Raman, in collaboration with K.S. Krishnan, had already made a significant contribution to the theory of molecular scattering of light. In recognition of his remarkable discovery which is universally known as the *Raman Scattering* or the *Raman Effect*, Raman was awarded the Nobel Prize for Physics in 1930. In the meantime, both Bose and Saha also became world famous for their fundamental discoveries in physical sciences. Bose's discovery was quantum statistics in 1924. Saha became well known for this contribution to the theory of ionization and its application to stellar atmosphere, and the equation that bears his name was first given in the paper 'On ionization in the solar chromosphere', published in the *Philosophical Magazine* in 1920. Within a short period of time, the University College of Science in Calcutta became well known as an institution of higher learning in the world.

In 1921, Bose was offered the position of Readership in the newly established Dacca University in East Bengal (now called Bangladesh). After some initial reluctance, he finally accepted this irresistible offer of promotion with increased salary. Although rank and salary considerations had never influenced his course of action, Bose moved to Dacca because he expected more academic freedom and better working conditions compared with those at the overcrowded University College of Science in Calcutta. In the physics department of Dacca University, Bose had the usual responsibility of teaching and guiding students in their research work. He studied various subjects extensively in order to be an effective teacher, especially teaching science through the mother tongue. In a new and conducive academic atmosphere in Dacca, Bose had quickly acquired a full and deep knowledge of classical thermodynamics and statistical mechanics as formulated by James Clerk Maxwell (1831-1879) and Ludwig Boltzmann (1844-1906). No doubt, more subsequent developments of these two subjects with applications to the equilibrium of chemical systems were made fully by the famous American physical chemist, Willard Gibbs (1839-1903). Perhaps, Gibbs made some outstanding contributions to thermodynamics and statistical mechanics which provided the basic mathematical tools for observable microscopic physical world. Certainly, he set the fundamental principles in greatest depth, breadth and mathematical clarity as described by M. Dutta (1968) in his article entitled "A Hundred Years of Entropy." In calculating the partition function and entropy, Gibbs recognized that entropy is not a strictly additive function. In fact, when two volumes of an ideal gas at the same temperature and pressure are mixed up, the resultant entropy is larger than the sum of the two entropies because the original order of individual volumes has disappeared, and the disorder of the system or its mixed-upness has increased. This is so called the *Gibbs Paradox.* Gibbs resolved this difficulty by an *ad hoc* procedure in dividing the partition function by the factorial of the number of particles in a given system. This division process simply avoids overcounting in the calculation of the canonical partition function.

Earlier in 1924 S.N. Bose had applied to Dacca University for a two-year leave for research and study abroad. A handwritten postcard from Albert Einstein stating that he regarded the first paper as a most important contribution settled the study leave issue in Bose's favor. The university granted him a research fellowship for a period of two years with full travel expenses.

This was adequate to maintain Bose in abroad and his family at home. Bose got his visa from the German consulate in Calcutta just by showing them Einstein's postcard without having to pay any fee for his visa. In early September of 1924, Bose sailed for Paris. After some stops for sightseeing on the way, he arrived in Paris in mid-October. Bose spent a year in Paris to work in the Laboratory of Madame Curie. At the same time, he has had the rare opportunity of meeting the several French physicists including Louis de Broglie, Paul Langevin and Maurice de Broglie. Bose learned some of the experimental techniques of X-ray spectroscopy and crystallography and also became interested in the properties of crystals. His experiences in Paris proved to be extremely rewarding and useful when K.S. Krishnan and his other students engaged themselves on important work on crystal physics in Dacca.

Both in his first letter of June 24, 1924, and his subsequent correspondence to Einstein, Bose addressed Einstein as "master" as in the classical Indian tradition. All Bose's letters to Einstein clearly show his deep respect, modesty and gratitude. Even after he attained fame as a great scientist of the world, his great respect and gratitude remained unchanged. In his letters from Paris, Bose expressed his strong desire of going to Berlin in order to have Einstein's 'inestimable help and guidance'. Finally, in early October 1925, Bose arrived in Berlin. Soon after his arrival, he wrote a one-line message to Einstein stating that he would welcome an appointment. Einstein was on his annual visit to Leyden at that time. Bose's life-long dream of meeting with Einstein took place only several weeks later when Einstein returned to Berlin. Although Bose's dream of working with Einstein never became reality, he did come into contact with Einstein and other world-renowned scientists including Fritz Haber, Otto Hahn, Richard von Mises, Michael Polanyi, Walter Gordon, Lise Meitner, Walter Bothe, Hans Geiger, Peter Debye, Von Laue, Wolfgang Pauli, Werner Heisenberg, and Eugene Wigner; many of whom were to receive the Nobel Prize. When they met, Einstein was curious to find out how Bose got the idea of deriving Planck's formula in an entirely new way. But Einstein was no longer interested in further research in statistical physics as he begun pursuing his quest for a unified field theory. Fortunately, with the help of a letter of introduction from Einstein, Bose had received several privileges including the right to use the library and to attend the physics colloquium. Bose had an exciting time in Berlin, especially he had the unique opportunity to discuss physics with Einstein and to know the current developments of quantum mechanics by W. Heisenberg, Max Born, P.M.M. Dirac, David Hilbert and others. Early in the summer of 1926, Bose went to Göttingen in order to attend a lecture of Max Born on quantum mechanics.

While he was in Berlin, Bose came to know from his friends that a position of professor of physics at the University of Dacca was vacant. He was somewhat reluctant to apply for this highest position because it required a Ph.D. degree. At the advice of his friends, Bose requested a letter of recommendation from Einstein so that he could apply for the position. Einsten was surprised at the request because he thought that Bose's scientific accomplishments were more than sufficient for the position. At the request of Bose, Einstein was pleased to send a letter of recommendation to the authorities of Dacca University indicating that Bose had come to Germany to their benefit. Finally, Bose was selected for the position of professor and Head of the Physics Department of Dacca University. In the late summer of 1926, Bose returned to Dacca and joined his highest academic position at a young age of 32. He remained in that position until 1945. During his long 22 year stay in Dacca, Bose pursued a series of theoretical as well as experimental research projects in collaboration with his postgraduate students. He had by then reached the summit of his life and one of the most respected personalities in the world of science. Indeed, Bose became a legendary figure in India, almost as much of a household name as Tagore and Gandhi.

In 1945, Bose returned to his 'Alma Mater' as the renowned Khaira Professor of Physics, and then held the Head of the Department of Physics from 1950-56. Among his numerous honors, Bose was elected President of the Physics Section of the Indian Science Congress in 1929. He became the General President of the 31st Session of the Indian Science Congress in Delhi in 1944. He was elected President of the National Academy of Sciences of India. In 1958 he was elected President of the Calcutta Mathematical Society and served the Society in that capacity for a period of three years. During his Presidency, the Society had organized the Golden Jubilee Celebration and published the Golden Jubilee Commemoration volumes in two parts. During his stay in Calcutta University from 1945-1956, he also served as Dean of the Faculty of Science for a few years. After his formal retirement from Calcutta University in 1956, he was appointed Emeritus Professor by the University. In the same year, he joined Visva-Bharati University at Santiniketan as its Vice-Chancellor.

In 1958, Bose was elected Fellow of Royal Society, London; and was also conferred the honor with title of 'Padma Vibhushan' by the President of India. In the following year, he moved from Santiniketan to Calcutta to become a National Professor associated with the University of Calcutta. With this prestigious status he got back his original office in the University College of Science which he occupied until his death on February 4, 1974. No doubt, his last position preceeded by a few honors and awards could be regarded as the climax of his academic career.

After his return home from Germany in 1926, Bose went abroad in 1951 and visited France. In 1953, Bose attended the World Congress for General Disarmament and Peace at Budapest at the invitations from the Soviet Union, Denmark and Czechoslovakia. During this trip to Eastern Europe, he visited Paris, Geneva, Zurich, Copenhagen and Prague. He met Wolfgang Pauli in Zurich and Niels Bohr in Copenhagen. In July 1954, he visited Paris again to attend the Third General Assembly of the International Union of Crystallography, and presented a research report on the studies of thermoluminesence spectra of alkali halides carried out by a group of his research associates at the Khaira Laboratory of Physics, Calcutta. After the conference, he went to Copenhagen in order to see Niels Bohr and then met G. de Hevesy as well. During his visit to Europe in 1954, S.N. Bose had a wish to go to the United States of America and wanted to see Einstein again. He expressed his feelings by saying: "I never met him afterwards [after 1926]. I was never in America. Some friends urged me to go to see him.' However, the McCarthy situation was active, and since I had happened to go to Russia before, they thought of me as a communist and did not give me a visa."

In 1962, S.N. Bose went to Sweden and from there to Moscow to attend the Peace Conference. In the same year he visited Japan to attend a conference on science and philosophy. This was organized in memory of the dropping of the atomic bombs for the first time over Hiroshima and Nagasaki in August 1945. He was very impressed with scientific, economic, social and cultural progress of Japan. From his visit to Japan, he gained first-hand experience of what the mother tongue could do for the science education of people. He had passionate concerns for the illiterate and poor people of India, and deep conviction that the problems of India could be solved by application of science and technology. On his return home he declared: "I have returned home from Japan firmly convinced about the necessity of adopting the language of the province [the different Indian states] as the medium of instruction in the university." With Rabindranath Tagore and Swami Vivekananda, Bose shared the conviction about the necessity of basic education through native language, and he remained convinced throughout his life.

Bose's ever increasing concerns for insufficient progress on education in general and science education in particular can be further described by quoting a part of Professor M. Dutta's 1973 article on Professor Satyendra Nath Bose - A Scientist: "Professor Bose had great power of analyzing every problem with deep insight. He realized that in a country where more than sixty percent of population are illiterate, the publication of a popular journal in mother-tongue is not sufficient. When the Parishad had its own house, at his inspiration and initiation, a hobby center for preparing models suitable for dissemination of knowledge and achievement of science and technology to common people (literate and illiterate) is established. ...Also in every meeting and the radio-broadcast he made an appeal to his fellow scientists to work hard for science and also for making India, united, progressive and powerful."

During the late 1930's and early 1940's, Bose became increasingly involved in the movement of Indian independence. He was elated with joy when India became independent on August 15, 1947 after nearly two hundred years of British rule. However, the partition of India in 1947 filled Bose with despair and grief. Though now settled in Calcutta, Bose could not accept this act simply because he greatly loved his native Bengal. Of course, there was really very little he could do. But he never forgot or forgave the British mischievous act of the partition of Bengal as well as the partition of India. In his 70th birthday commemoration volume 1, N.N. Ray described Bose's deep patriotic feelings for his homeland as "He loves Bengal as he knew her from his boyhood through maps and travels; he loves her history and literature, her arts and music, her political and economic aspirations. So long as a man is a Bengali, the difference in religious creeds mean nothing to him. The image of India that he carries in his heart stands for India of pre-independence days. Our independence has lost much of its meaning to him - because of the partition." Immediately after independence of India, Bose was deeply disturbed by large illiterate population of India. So he became actively involved with various activities in support of social and economic reforms and mass education with special emphasis on science. He also realized that industrial and technological advancement in free India can be achieved only through science education among people. In addition to his great concerns for social, educational and economic problems, he became increasingly involved in promotion and dissemination of science to common people through their mother tongue. In 1935, he wrote an article on 'Einstein' in a Bengali magazine called *Parichaya* (Introduction). While he was in Dacca, Bose persuaded a group of young scientists centered around him to publish a popular monthly science magazine in Bengali language. Under his leadership, a science magazine in Bengali called *'Bijnan Parichaya'* (Introduction to Science) was established at Dacca in 1941. Bose was used to teach physics courses in Bengali in both Dacca and Calcutta. Within a few years after his return to Calcutta, he provided a unique leadership to establish an organization in Calcutta called *'Bangiya Bijnan Parishad'* (Science Association of Bengal) whose main objectives were promotion and dissemination of scientific knowledge to common people in Bengali, and preservation of Bengali culture. In 1948, Bose started a monthly popular science magazine in Bengali named as *'Jnan O Bijnan'* (Knowledge and Science). It is still published regularly. He used to contribute semipopular scientific articles to it. His success did not come merely from intelligence but from deeper gifts of character that enabled him to set up the effective organizations and media of the kind he needed. In order to create interest and excitement among very young people in West Bengal, Bose also became interested in exhibiting scientific knowledge and discovery in the form of a simple and popular model. When the Bijnan Parishad (Science Association) had its own building in North Calcutta, he had also asked the Parishad to create a *'Hobby Center'* for preparation of scientific and engineering models suitable for exhibition to common people, especially to school children. These activities with his own involvement clearly indicate that Bose strongly believed that science education in native language would serve a very useful purpose to our society. He maintained this belief to the end of his life.

Perhaps the most remarkable feature of Bose's personality is that he himself believed in serious and effective teaching based upon extensive and critical study of the original research papers of the great masters like Maxwell, Boltzmann, Planck, Einstein, Bohr and Sommerfeld. As a classroom teacher, Bose was exceptionally different in the sense that he used to develop the subject in the class in his own style from the fundamental notions, sometimes giving his own treatment with open questions or unsolved problems. From this experience he developed the motto which he used to impress upon his students. One of his students N.D. Sengupta wrote about S.N. Bose who once said: "Never accept an idea as long as you yourself are not satisfied with its consistency and the logical structure on which the concepts are based. Study the masters. These are the people who have significant contributions to the subject. Lesser authorities cleverly bypass the difficult points." His method of teaching was not only stimulating, but also useful for those who would be seriously interested in advanced study and research. Bose always made time available to spend with his students and research associates. He set out to encourage personal initiative and directed his research students on a very informal and friendly basis – they were encouraged to come to his office or home and start discussing their problems. Despite his high standards and demands, his research students found him quite informal and easy to work with. Bose also had the rare ability to inspire enthusiasm for study and research. Indeed Bose was a great teacher. The long line of his distinguished students is testimony not only to his effectiveness as a teacher, but to his personal qualities which attracted them and kept so many of them in Dacca and Calcutta. Bose had a special love for informal discussions or seminars on any topic concerning mathematics, physics, chemistry or even botany. He always emphasized that teaching and research should be considered as a noble mission of a professor's life rather than a profession. He often used to conduct experiments in his chemistry laboratory or in his X-ray laboratory, because of his diverse interest in theoretical and experimental research. According to Bose, mathematical theory plays a dual role in physical science. It serves to interpret observations, but more importantly, it provides a basis analogous to *experiments* in physics, chemistry and biology.

S.N. Bose simply hated the caste system that hindered the progress of the entire Indian nation. He felt a profound moral obligation to use his unique influence to save Indian civilization from such destructive rules. One of the primary reasons why he had great respect and admiration for Buddha was that Buddhism struck a blow at the caste system because it taught universal brotherhood and love. The year 1974 marked the 80th birth anniversary of S.N. Bose and the 50th anniversary of the publication of the Bose-statistics. In his 80th birthday celebration organized by the Calcutta Mathematical Society, Bose made a lively and characteristic speech of thanks that rejoiced his old students and colleagues from all over India. He firmly declared his genuine hatred toward the caste system in even stronger words (Dutta, 1973): "...One thing in this casteridden country people quarrel among themselves about how they were born and so on. These things still persist even though Gandhiji had preached the removal of these things... ...In India what we really need in really a sort of total abolition of all the racial spirits, the spirits of dissension that still troubles us occasionally to such an extent that we old people really get lost and we could not guess as to where our young people are being led on. But I hope, this very few people who are still at the helm, who in spite of all difficulties still really believe in the high ideals in India, still think that India has got something to play to the World to give to the World the spirit of cooperation and love of humanity." Even after almost half a century later of Indian independence, his thoughts and words have a great value in inspiring the thousands of men and women who are engaged in nation-building activities in India.

In 1964 Bose's 70th Birthday Celebration was organized in Calcutta. The Calcutta Birthday Celebration Committee published a Commemoration Volume in three parts. The First Part contains a brief sketch of S.N. Bose's life and scientific activities and also his published research articles. The Second Part consists of scientific research papers contributed by eminent scientists from all over the world. As a part of the 70th Birthday Celebration, two symposia on "Forty Years of Bose Statistics" and the "The Unified Field Theory" were organized during the 51st and 52nd Sessions of the Indian Science Congress in Calcutta in January 1965. All papers presented at the two symposia were published in Part III of the Commemoration Volume. The Delhi University also celebrated his 70th birthday with a symposium on "Forty Years of Bose Statistics" and presented him a volume containing research articles on Bosons which illustrate the great impact of Bose's 1924 work on contemporary physics.

In Part I of the S.N. Bose 70th Birthday commemoration volume, N.N. Ray described Bose's views on humanity as: "His faith in the ultimate glory of humanity is based on a relentless pursuit of objective truth, the spirit of inquiry that is embodied in science, the service to mankind from the stand-point of irresistible social evolution to higher and higher levels of existence. He knows the immense 'power of a lie', that is why he believes in constant readiness to fight whatever retards human progress." Bose maintained this honest attitude to the end of his life. With a touching personal tribute, Bose once said: "Of all human beings ever born, I revere Gautama Buddha most." He had great faith in the survival and spiritual growth of humanity. He profoundly believed in the pursuit of objective truth through science and in selfless service to mankind.

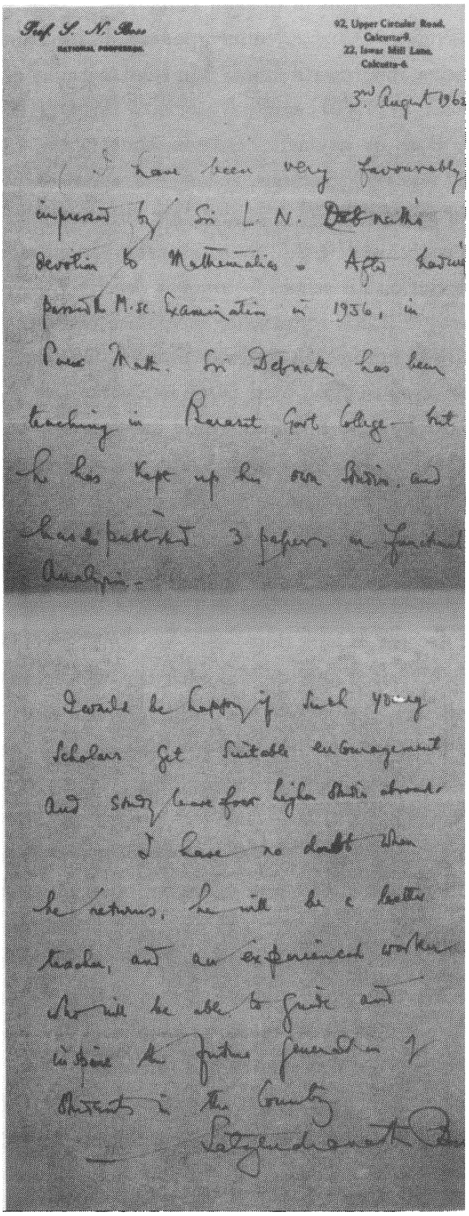
There is no doubt at all that the man-scientist duality of Albert Einstein (Debnath, 1979) was a major influence on Bose's life and thought. The profound respect that Bose had for Einstein can accurately be described by his writing about his great Guide in Bengali: "His personality as a man was beyond compare. He never lowered his head to violence and unreason. His faith in man was unlimited. He had to suffer much in life - and so he had an extra tenderness for the younger devotees of science. ...He did not bow to Hitler and Mussolini. In the last stage of his life when America, following his researches, found out the clue to nuclear power and used to to vast human death and destruction - he did not hesitate to openly record his protest against such inhuman behavior." Bose's early research and its immediate recognition by Einstein had made his name famous in modern physics. So he remained grateful to Einstein for his help and encouragement he had received from him throughout his life.

Bose's great concern on the shortage of energy can be best described by his own words from his inaugural address delivered in his 80th birthday celebration at the Calcutta Mathematical Society in 1973: "Well, we are able to solve our problems ourselves and at the same time to solve the problem of oil which really faces us. ...But I think now people should really think how to get together, how to utility, some people already talked of, the enormous power that is developed by the waves, etc. as they have already done. In other countries they tried that sea waves could be utilized for generation of power. I think there should be things done not only to solve our problem for the time to come but also at any rate to show that to the world so long as science grows. I think it will be possible for us keeping the right spirit of cooperation among humanity to keep the humanity living in this civilization progressively in spite of various difficulties that look forward, in spite of the vanishing reserves in resources..." His unbounded enthusiasm for science was shared with his students and colleagues, and he also encouraged them to seek solution of a problem by new methods.

In spite of the acclaim of the scientific world, Bose was a modest man, kind and friendly. Music was one of his early loves and his interests ranged from folk music to classical as well as from Indian to Western. In addition, he had taken keen interest in Bengali literature all his life. Once Professor Suniti Chatterjee, a renowned scholar of Bengali language and literature, showed him his big book manuscript on "The Origin and Development of Bengali Language". Bose had made a few original and useful suggestions which Professor Chatterjee incorporated in his famous book. This is another example of S.N. Bose's creative and versatile mind. In the biography of S. Chandrasekhar (a Nobel Prize winner in Physics in 1983) written by K.C. Wali (1991), Chandrasekhar expressed his opinion about S.N. Bose by saying: "Bose in some ways, from human point of view, was the best of them all. He was very generous, gentle, easygoing, and not particularly caring about the glamorous aspects of science." What is less easy to convey is his well developed sense of humor, lack of pomposity and good companionship in personal relationships. Perhaps one of the best recorded stories on his sense of humor is described by one of his research students, Gaganbehari Bandopadhyay in 1987: "Professor S.N. Bose and some of his disciples went to receive Professor and Mrs. Dirac at Howarh Railway Station. When they arrived, Professor Bose took them to the car, made Professor and Mrs. Dirac sit on the rear seat, and started pulling all his disciples to him in the front seat. Here came an occasion when Professor Dirac spoke. He said 'What are you doing?' Our moody and affectionate Professor Bose laughed and said: 'We believe in Bose Statistics.' Professor Dirac immediately explained to Mrs. Dirac 'In Bose Statistics things crowd together'."

Perhaps it is appropriate to record here my personal relationship and association with my grandteacher Professor S.N. Bose. When I was a post-graduate student at Calcutta University, I learned a lot of interesting reminiscences and stories about Bose and his great scientific achievements from my teacher and major research advisor, Professor Mahadeb Dutta, who was a true disciple and friend of Professor Bose. Professor Dutta had not only received research guidance from Professor Bose, they shared a lot of common views and interests in social and academic matters. I first saw Bose at the condolence meeting held at the Senate House of the University of Calcutta on April 18, 1955 to pay a special tribute and last respect to Albert Einstein. Soon after Einstein's death Bose wrote: "During the upheavals between the two World Wars Einstein suffered much. In 1933 he was forced to leave Berlin and robbed of all his possessions. ...His indomitable will never bowed down to tyranny, and his love of man often induced him to speak unpalatable truths which were sometimes misunderstood. His name would remain indissolubly linked up with all the daring achievements of physical science in this era, and the story of his life a dazzling example of what can be achieved by pure thought." No doubt Bose had received a good deal of inspiration from the work and personality of Einstein.

During my stay in Calcutta, I attended many public or private lectures of S.N. Bose. Immediately prior to the Golden Jubilee Celebration of Calcutta Mathematical Society in 1958-60, Professor Dutta introduced me to Professor Bose. Thereafter I have had numerous opportunities of seeing S.N. Bose in his office at the University College of Science and his home at 22 Iswar Mill Lane, North Calcutta. In fact, his influence on me can be traced back to my high school days in Dacca, well before I met him in Calcutta, and heard his lectures and read some of his articles. I was, indeed, fortunate and grateful for his own hand-written letter of recommendation in support of my application for admission to a Ph.D. program in British universities. It is my pleasure to display the letter here to record his kind encouragement and interest in an ordinary student like me. It was with pride and pleasure that Professor Dutta and I dedicated our first book on Elements of General Topology to Professor S.N. Bose in 1964. So my desire as well as interest in writing this centennial tribute commemorating S.N. Bose the man and the scientist is founded solely on my deep respect and admiration for this great man and renowned scientist whom I had the opportunity of knowing fairly well.



Prof. S. N. Bose
NATIONAL PROFESSOR

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3rd August 1962

I have been very favourably impressed by Sri L. N. Debnath's devotion to Mathematics. After having passed the M.Sc. Examination in 1956, in Pure Math. Sri Debnath has been teaching in Barasat Govt College but he has kept up his own studies, and has published 3 papers in Functional Analysis.

I would be happy if such young scholars get suitable encouragement and study leave for higher studies abroad. I have no doubt when he returns, he will be a better teacher, and an experienced worker who will be able to guide and inspire the future generation of students in the country.

Satyendranath Bose

S.N. Bose: Playing with Esraj

S.N. Bose with his house cat

2. SIGNIFICANT SCIENTIFIC CONTRIBUTIONS.

Bose's first important contribution to statistical mechanics was two joint papers with M.N. Saha on the influence of finite volume of molecules on the equation of state. They were published in the *Philosophical Magazine* in 1918 and 1920. The equation formulated in this work is generally known as the **Bose and Saha equation of state**. This equation for the pressure p in terms of volume V and temperature T is

$$p = -\frac{NkT}{2b} \log\left(1 - \frac{2b}{V}\right), \tag{2.1}$$

where N is the number of molecules with finite volume b and k is the Boltzmann constant. In the first approximation ($b \ll V$), (2.1) gives the classical Boyle-Charles law, $pV = NkT$. In the second approximation, the Bose and Saha equation reduces to the classical van der Waals equation, $p(V-b) = NkT$ without the term a/V^2 involved in p arising from the existence of intermolecular forces.

In 1919, Bose published two papers in the *Bulletin of the Calcutta Mathematical Society*. They deal with the solution of stress equations of equilibrium in elasticity, and a simple proof of non-existence for the point of inflexion of the horpolhode.

Bose's fifth paper "On the deduction of Rybderg's law from the quantum theory of spectral emission" was published in the *Philosophical Magazine* in 1920. Based on the old quantum theory of spectral emission due to Bohr and Sommerfeld, Bose calculated the energy of a many-electron atomic system neglecting the influence of the moving electron on the arrangement of the other electrons surrounding the nucleus so that the potential can be approximately represented by $(-r^{-1}e^2 + r^{-2}\, L \cos\theta)$. Application of the Sommerfeld-Wilson quantum rule

$$hn_i = \int p_i \, dq_i. \tag{2.2}$$

led Bose to derive the energy of the system as

$$W = -\frac{Nh}{(n + n_3 + z)^2}, \quad n + z = y, \tag{2.3}$$

where n is the azimuthal quantum number, n_3 is the radial quantum number and z is a function of n only. He then used the Sommerfeld principle to find a single value for the energy of the s-orbits ($n=1$), a double value for the energy in the p-orbits ($n=2$), a triple value for the d-orbits ($n=3$). He also derived the Rydberg laws of regularity in spectral series of elements on the basis of Bohr's quantum law $h\nu = W_n - W'_n$, and then successfully applied the laws to the case of alkali metals. Bose conjectured that, if L varies with the radial quantum number, his calculation would lead to Ritz's law. This was the first of a total of five papers which Bose wrote on various aspects of quantum physics.

In 1900, Planck proposed a new revolutionary hypothesis for the derivation of the energy distribution of the black body radiation which deals with the electromagnetic radiation in a container in equilibrium with its surroundings. In other words, the black body radiation is essentially concerned with thermodynamics of the exchange of energy between radiation and matter. According to classical principles, this exchange of energy was assumed to be *continuous* in the sense that light of frequency ν can give up any amount of energy on absorption, the exact amount in any particular case depending on the energy intensity of light beam. But Planck's new hypothesis requires that the energy exchange between radiation and matter is *discrete*. In other words, he postulated that the vibrating particles of matter is regarded to act as harmonic oscillators and do not emit or absorb light continuously, but instead only in *discrete* quantities of magnitude, $E = h\nu$ where h is the Planck constant. Indeed, Planck considered the light quanta or *photons* as the electromagnetic waves. With direct or indirect use of this classical idea of electromagnetic theory, Planck (1900), Peter Debye (1910), and Einstein (1917) independently derived the Planck radiation formula for the energy in the radiation from a black body. All these authors were faced with some kind of difficulties, but they had never been able to resolve them.

The first and most famous of Bose's 1924 papers is a four page paper entitled "Planck's law and the light quantum hypothesis" which marked the beginning of quantum statistical physics. The thirty year old Bose was the first to challenge the classical statistical mechanics and totally abandoned Planck's wave aspects of photons. He then gave an entirely new and novel derivation of the Planck radiation formula for energy based upon a systematic *phase-space argument* of statistical mechanics without any assumptions of the classical electromagnetic theory, and submitted a paper on this work to the *Philosophical Magazine*. Six months later the paper was rejected because of the negative recommendation by the referee. Bose then sent the rejected manuscript to Albert Einstein in Germany with a handwritten cover letter on June 4, 1924. Einstein promptly acknowledged Bose's letter with paper in a handwritten postcard stating that "he regarded the paper as an important contribution and he will have it published." He was very impressed with Bose's paper, especially because Bose's derivation is totally independent of the wave treatment of photons. Einstein instantly translated the paper himself into German under the title "Planck's Gesetz und Lichtquantenhypothese," and got it published in the 1924 August issue of *Zeitschrift für Physik* in Bose's name with a short complimentary comment added: "Bose's derivation of Planck's formula appears to me an important step forward. The method used here gives also the quantum theory of an ideal gas, as I shall show elsewhere [A. Einstein]."

Bose was the first mathematical physicist in the world who gave a completely general and logical formulation of quantum statistics. With the new idea of microstates taking into account the identity of the particles, he simply assumed a micro ensemble of n indistinguishable particles of all frequencies in a state of equilibrium at a given temperature and determined the most probable distribution of these particles among all energy states in the system. His main goal was to determine the probability distribution subject to the conditions that the total energy $\varepsilon = \sum_i n_i \varepsilon_i$ is constant, and the total number of particles $n = \sum_i n_i$ is also constant (except for the case of photon particles). In Bose's formulation of quantum statistics, there is no restriction on the number of particles in any eigenstates. The energy spectrum can be described by the number of energy eigenstates $g_i = f(\varepsilon_i)\Delta\varepsilon_i$ is a continuous function of energy ε_i. Then the application of the method of Lagrange's undetermined multipliers leads to the most probable distribution

$$n_i = \frac{g_i}{[exp(\alpha + \beta\varepsilon_i) - 1]} \tag{2.4}$$

where α and β are undetermined constants which depends on the number and kind of particles in the system, and on the equilibrium condition of the system. However, in general, $\alpha = -\frac{\mu}{kT}$ and $\beta = \frac{1}{kT}$ where k is the Boltzmann constant and μ is referred to as chemical potential. Consequently, distribution (2.4) becomes

$$n_i = \frac{g_i}{[exp\{(\varepsilon_i - \mu)/kT\} - 1]} \tag{2.5}$$

This is universally known as the *Bose* (or the *Bose-Einstein*) *distribution function.*

In order to derive the Planck law for the energy distribution of black-body radiation, Bose treated radiation as *photon particles.* Indeed, he assumed that photons are *indistinguishable, identical* and *massless* particles of energy $\varepsilon = h\nu$ and momentum $p = \frac{h\nu}{c}$ where c is the velocity of light. This new conception of radiation is one of the most fundamental discoveries of Bose. To determine the distribution of photons over the various energy levels, Bose made use of the relationship between the number of photon states in the frequency range ν to $\nu + d\nu$ and the volume of the relevant region of the phase space with the result

$$dg = g(\nu)d\nu = 2 \cdot \frac{V}{h^3}\left[4\pi \left(\frac{h\nu}{c}\right)^2 \cdot \frac{h}{c}\, d\nu\right] = \frac{8\pi\nu^2 V}{c^3}\, d\nu, \tag{2.6}$$

where g_i is replaced by dg which represents the number of elementary eigenstates in the frequency band $d\nu$, and the factor 2 is introduced because there are both left-handed and right-handed photons and so it is physically justified. Thus, in an enclosure of volume V, the number of photons dn_ν in the range ν to $\nu + d\nu$ is given by the *Bose distribution law*

$$dn_\nu = \frac{g(\nu)d\nu}{\left[exp\left(\frac{h\nu}{kT}\right) - 1\right]} = \frac{8\pi V}{c^3} \frac{\nu^2}{\left[exp\left(\frac{h\nu}{kT}\right) - 1\right]}\, d\nu, \tag{2.7}$$

since the chemical potential μ for photons is zero.

The number of photons per unit volume is $\frac{dn_\nu}{V}$, and hence the energy per unit volume in the range ν to $\nu + d\nu$ or simply the energy density $E(\nu)d\nu = h\nu \cdot \frac{dn_\nu}{V}$ in the frequency band $d\nu$ is

$$E(\nu)d\nu = \frac{8\pi\nu^2}{c^3} \cdot \frac{h\nu}{\left[exp\left(\frac{h\nu}{kT}\right) - 1\right]}\, d\nu. \tag{2.8}$$

This is the famous **Planck radiation law** which has an excellent agreement with several experimental findings. This law was derived by several others based on the assumption of radiation as electromagnetic waves. Thus Bose's derivation of the Planck law *without* any assumption of classical electromagnetic theory for the first time triumphantly established the *particle* concept of electromagnetic radiation.

In the limit of low frequency ν and high temperature $T(h\nu \ll kT)$, the Planck law reduces to the classical Rayleigh-Jeans formula

$$E(\nu)d\nu \approx \frac{8\pi\nu^2}{c^3} \cdot kT \cdot d\nu. \tag{2.9}$$

This result was in excellent agreement with observations for low frequencies, but *not* for high frequencies. This striking disagreement at high frequencies is to be expected because the total energy E of radiation per unit volume is

$$E = \int_0^\infty E(\nu)d\nu = \infty. \tag{2.10}$$

This infinite value for the energy is clearly unacceptable on physical grounds because the total energy can be measured, and hence it must be finite.

On the other hand, in the limit of high frequency ν and low temperature $T(h\nu \gg kT)$, Planck's formula (2.7) agrees with the classical Wien's radiation law

$$E(\nu)d\nu \approx \frac{8\pi h\nu^3}{c^3}\, exp\left(-\frac{h\nu}{kT}\right) d\nu. \tag{2.11}$$

However, this result disagreed with all experimental findings in the range of very low frequencies. And for small ν and large T, Wien's law does not lead to the Rayleigh-Jeans result (2.9). Above all, (2.11) was derived by Wien based on unacceptable theoretical foundations. So the Wien's law is not valid, and must be replaced by the Planck law which satisfied all possible requirements.

Finally, the total energy density of black body radiation at a given temperature T is obtained by integrating (2.8) so that

$$E = \int_0^{\infty} E(\nu)d\nu = \sigma T^4 \tag{2.12}$$

This result is known as the *Stefan-Boltzmann law* and σ is called the *Stefan constant*. Physically, this represents the total energy flux which gives the rate at which energy is radiated per unit area.

It was rather a fortunate coincidence that Bose discovered his quantum statistics just when de Broglie was developing the theory of wave-particle duality of matter. Since Bose's statistics can be derived as a consequence of the wave nature of particles, it may well be predicted that Bose would have discovered the theory of electron waves if de Broglie had not done so in 1924.

Just eleven days after sending his first paper and letter to Einstein on June 15, 1924, Bose sent his second paper on "Thermal equilibrium in the radiation field in the presence of matter" with a request for its publication in a suitable journal. Einstein also translated this German and submitted to *Zeitschrift für Physik* when it was published in its 1924 August-September issue. This paper contained a most general and new result on radiation equilibrium. This work formed a bridge between quantum statistical mechanics and the kinetic theory, and is completely free from any classical model assumptions. No doubt, Bose's second paper is not only mathematically more elegant than the first one, but also physically more sound, and was based upon the experimental findings of Debye (1923) and Compton (1923) on scattering of photons by electrons. Even today this work remains unknown due to Einstein negative comments on Bose's paper.

Within six months of the Bose's derivation of Planck's law, Wolfgang Pauli (1925) first formulated a new fundamental law relating to electron states to explain some experimental observations in spectroscopy. This is universally known as the *Pauli Exclusion Principle* which states that no two electrons in an atom can occupy exactly the same state. It should be pointed out that in the Bose statistics there is no restriction on the number of particles in the same state. Perhaps inspired by Bose's work, in 1926 Enrico Fermi used successfully the Pauli Principle to discover another new but famous quantum statistics of degenerate matter. This work of Fermi was also published in *Zeitschrift für Physik*. The distribution law for the Fermi statistics is given by

$$n_i = \frac{g_i}{[exp(\alpha + \beta\varepsilon_i) + 1]} \tag{2.13}$$

It is noted that both the Bose statistics and the Fermi statistics approach the Maxwell-Boltzmann statistics when $n_i \ll f_i$, since $exp(\alpha + \beta\varepsilon_i)$ would then be very large compared with unity.

The Fermi statistics later became known as the *Fermi-Dirac statistics* because of Dirac independent research which was published about six months later than Fermi's paper. It became clear from the fundamental work of Dirac and Pauli that particles obey Bose-Einstein statistics are called *Bosons* after the name of Bose and a system of Bosons can be described by a totally symmetric wave function. Particles that obey the Fermi-Dirac statistics are known as *Fermions*. A system of Fermions can be described by a totally antisymmetric wave function. On the other hand, relativistic quantum mechanics established a remarkable connection between statistics and spin. Bosons possess zero or integral spin ($s = 0, 1, 2, \cdots$) and Fermions have half-integral spin ($s = \frac{1}{2}, \frac{3}{2}, \cdots$). Thus photons, helium nuclei, π and K mesons are Bosons, whereas electrons, protons, neutrons, μ mesons are Fermions. According to Dirac: "All the particles in nature are Fermions or Bosons. Thus they occur only antisymmetric or only symmetric states of the same particles." No doubt, Bose made a most fundamental discovery of modern physics before the birth of quantum mechanics. It still remains a mystery in the history of science why Bose was never awarded a Nobel Prize for his fundamental discovery.

It was Albert Einstein who first recognized the deep significance of the Bose statistics, and later he himself extended Bose's ideas and results to develop the quantum theory of ideal gases. Subsequently, Einstein clearly demonstrated that the Bose statistics is not limited to photons, but can be successfully applied to material particles (or molecules) as well since the Bose statistics led to a new distribution function significantly different from the classical Maxwell-Boltzmann distribution, and hence to a different equation for a perfect gas. In case of an ideal Bose gas with non-zero chemical potential ($\mu \neq 0$), there exists a critical temperature T_c below which a finite fraction of the gas condenses into a *single quantum* state with zero energy ($\varepsilon_1 = 0$). This process of accumulating particles into the zero-energy ground state is known as *Bose-Einstein Condensation Phenomenon.* It was first predicted by Einstein in 1925 and its full significance was given by him with the aid of the Bose statistics. Thus a Bose gas at temperatures $T < T_c$ is called *degenerate* and the critical temperature T_c is known as the *degeneracy temperature* or the *condensation temperature.* Such degeneracy has never been observed in the classical theory. However, for temperatures $T > T_c$, the number of particles of the Bose system is quite negligible. It was also predicted that the specific heat is continuous at $T = T_c$, but its derivative with respect to T is discontinuous at $T = T_c$. This property is characteristic of the occurrence of a phase transition as supported by several experimental observations.

Thirteen years later, London (1938) proved that the Bose-Einstein Condensation phenomenon is the basis for a microscopic understanding of the curious properties of liquid helium at low temperatures. According to London, the curious phase transition that occurs in liquid He^4 at a sharply defined temperature of 2.19°K is a manifestation of the Bose-Einstein condensation. The phase above this transition temperature is known as helium I and that below it is called helium II which is a very peculiar fluid. It behaves like a mixture of two fluids – the normal viscous fluid and the super fluid, and there is no viscous interaction between these two fluids. The normal fluid possesses all the usual features of a fluid. The super fluid has remarkably curious properties of a fluid. It has zero entropy, and apparently no viscosity indicating that it experiences no resistance to its flow. This ultimately led to modern development of the theory of super fluids by Landau (1941).

During the 1930's and 1940's, Bose's active research interest shifted from one area to another. Towards the middle of 1936 and the beginning of 1937, Bose wrote two original papers on mathematical statistics and got them published in the famous Indian statistics journal, *'Sankhya'.* Both papers deal with the moment coefficients of the D^2-statistic and certain integral and differential equations associated with the multivariate normal population. His work can be described briefly with a short background information as follows. P.C. Mahalanobis (1930) first introduced the D^2-statistic to measure the divergence between two statistical populations and then calculated the moment-coefficients by approximate methods. In his two original papers, R.C. Bose (1936ab) obtained the exact distribution of the D^2-statistic which can be expressed in terms of Bessel functions, and then used the actual distribution function to calculate the moment-coefficients. In the same year, S.N. Bose proved a fundamental recurrence relation satisfied by the solid moments, and an ordinary differential equation satisfied by them. He then obtained an expression for the distribution function in terms of moments. He also derived the fundamental recurrence relation for the kth raw moment of $\mu'(D_1^2)$ of $D_1^2 = D^2 + \frac{2}{n}$. He had shown that $\mu_k'(D_1^2)s$ belong to a Gaussian distribution in p-variables and they satisfy differential equations which admit polynomial solutions of integral order m. Some properties of these equations are found to be useful for determination of the form of the general distribution function. He had also shown that the distribution function can be calculated in terms of moments.

As a follow up of this work, Bose published another paper in 1937 on the moment-coefficients of the D^2-statistics and certain differential and integral equations associated with multivariate normal distribution. Based upon certain algebraic identities derived from the polynomial form of the moment-coefficients of the D^2-statistic, and the algebraic identities obtained from the differential form of the moment-coefficients, he obtained a number of fundamental differential and integral equations associated with the multivariate normal distribution, and their solutions in terms of the Sonnie polynomials of an integral order. Finally, he proved that the general form of the distribution function in (R, t) is

$$\sum (2\pi t)^{-\frac{p}{2}} exp\left(-\frac{R^2}{2t}\right)\left[A_0 + \frac{A_1}{t^2} S_1\left(\frac{R^2}{2t}\right) + \frac{A_2}{t^4} S_2\left(\frac{R^2}{2t}\right) + \cdots\right] \tag{2.14}$$

where $R^2 = \sum_{n=1}^{p} x_n^2$, $t = \frac{2s}{u}$, $S_k(x)$ is the Sonnie polynomials and the coefficients A_0, A_1, A_2 can be calculated in any particular case when the moments of the modulus distributions are known.

In his 1938 paper "On the Total Reflection of Electromagnetic Waves in the Ionosphere" published in the *Indian Journal of Physics*, Bose recognized certain difficulties involved in the reflection of radio waves in the upper atmosphere. He then first gave a new microscopic formulation of the problem based upon the Lorentz equations instead of using the classical Maxwell equations with complex refractive index. He solved the problem by developing a very general method of mathematical analysis. His method is very general in the sense that it is suitable for problems of refractive-index of material media as well as for an investigation of wave propagation in the upper atmosphere. Also it seems further amenable to modifications to suit the requirements of modern wave mechanics. During the 1960s various theoretical methods including Sen and Whyller (1960) and experimental techniques have been developed to study the microscopic and macroscopic properties of the ionosphere. In collaboration with S.R. Khastgir, Bose also reported his findings on the anomalous dielectric constant of artificial ionosphere in 1937. It became clear from their work that Bose's contribution to this area had also served as the basis of subsequent developments of the subject.

In the following year (1939) Bose published a paper entitled "Studies in Lorentz Group" in the *Bulletin of the Calcutta Mathematical Society*. In this paper, he proposed a purely algebraic method to obtain the decomposition of the Lorentz group into two commutable factors. In 1941 he published his work on the complete solution of the inhomogenous scalar Klein-Gordon equation in the *Proceedings of the National Institute of Science,* India. In view of the importance of the equation and its solution in H.J. Bhabha's research on mesons, Bose gave two methods of solution of the Klein-Gordon equation. Three years later, he gave a new treatment of Sonine's polynomials, and published his work in the *Indian Journal of Physics* in 1943. Bose's last paper on quantum mechanics deals with an integral equation associated with the equation for hydrogen atom which appeared in 1945.

As General President of the 1944 Indian Science Congress, Bose delivered his Presidential Address on "The Classical Determinism and the Quantum Theory". This is a unique address in the sense that it is still as thought stimulating today as it was then. He introduced the subject by stating:

"Fifty years ago the belief in causality and determinism was absolute. Today physicists have gained knowledge but lost their faith."

He concluded with these words:

"The theory has brought hope and inspired activity. It constitutes a tremendous step towards the understanding of nature. The features of the present theory may not all be familiar but use will remove the initial prejudice. We are not to impose our reason and philosophy on nature. Our philosophy and our logic evolve and adjust themselves more and more to reality.

In spite of the striking successes of the new theory, its provisional character is often frankly admitted. The field theory is as yet in an unsatisfactory state. In spite of strong optimism, difficulties do not gradually dissolve and disappear. They are relegated to a lumber room, whence the menace of an ultimate divergence of all solutions neutralizes much of the convincing force of imposing mathematical symbols. Nor is the problem of matter and radiation solved by the theory of complementary characters. Also we hear already of the limitations of the new theory encountered in its application to nuclear problems.

The quantum theory is frankly utilitarian in its outlook; but is the ideal of a universal theory completely overthrown by the penetrating criticism of the nature of physical measurements?

Bohr has stressed the unique character of all physical measurements. We try to synthesize their results and we get probabilities to reckon with instead of certainties. But how does the formalism $\frac{h}{2\pi i}\frac{\partial\Psi}{\partial t} = H\Psi$ emerge as a certain law? The wider the generalization, the less becomes the content. A universal law would be totally devoid of it. It may nevertheless unfold unsuspected harmonies in the realm of concept. More than ever now, physics does need such a generalization to bring order in its domain of ideas."

Shortly after his return to Calcutta from Dacca, S.N. Bose and his collaborators had initiated experimental research on the thermoluminescence of solids irradiated by X-rays or low energy electron beams. *Thermoluminescence* means the phenomenon of emission of light (including infrared and ultraviolet radiation) other than pure thermal radiation, by a system under thermal stimulation. When a system is excited by any method and a part of the excited energy is stored in it, the system is called *thermoluminescent* if a part or whole of the stored energy is released in the radiant form on heating. So the phenomenon of thermoluminescence exhibits a wide variety of behaviors corresponding to different materials with variation in impurity contents or other imperfections. Thus, in general, the duration of thermoluminescence is of the order of a minute and afterglow emission. Comparatively poor in intensity, may also change in spectral composition as the intensity changes with time. The perplexing difficulty of interpretation was thus essentially due to the lack of a suitable measuring device and experimental techniques. In order to gain a better understanding of the mechanism of luminescence in general and thermoluminescence in particular, it has been necessary to determine the spectral distribution of the emission process. Bose and his research associates first used spectroscopic cum photometric methods to analyze the thermoluminescence spectra of pure and impurely activated alkali halides in the Khaira Laboratory of Physics at the Calcutta University. It was found that experimental peaks in the thermoluminescence glow curves differ in the spectral nature of the emission. All attempts to record these peaks spectrographically had failed. This is because of the low intensity and transient nature of the emission spectra which made it impossible to record this spectral distribution except with the most sensitive light detecting device. Bose recognized the crux of the problem and designed a rapid scanning spectrophotometer of relatively high sensitivity to meet the requirements of the experimental technique. He reported the design, construction and fabrication of a rapid scanning spectrophotometer capable of recording the spectral distribution of the peaks in the thermoluminescence glow curves in one second at the International Conference on Crystallography held in Paris in 1954. Under his unique guidance, B.C. Dutta and A.K. Ghosh had carried out experimental research at the Khaira Laboratory of Physics on the thermoluminescence spectra of alkali halides. Their findings were reported for the first time in 1956. So Bose's ingenious ideas and methods in the field of thermoluminescence were subsequently used in different laboratories throughout the world.

In the first quarter of this century, Einstein's theories of relatively produced a great deal of interest and excitement in the whole world. The theories made several remarkable predictions about the physical world that were readily understandable, and were, in principle, amenable to experimental tests. His other notable and testable predictions included the bending of light by a gravitational field, the gravitational shift of the spectral lines, the correct perihelion motion of Mercury, and the bending of rivers due to the Coriolis force. All of the predictions had received conclusive experimental confirmation. Newspapers, popular magazines, and scientific journals were full of articles about these theoretical and experimental findings. As early as 1920 Bose's interest in relativity had been aroused after reading Einstein's papers on the subject. In collaboration with M.N. Saha, Bose translated original papers by Einstein and H. Minkowski from German into English, and then published them in the form of a book (1920) entitled "*The Principles of Relativity*" with a historical introduction written by a famous Indian statistician, P.C. Mahalanobis. During his meeting with Einstein in Berlin in 1924, Bose came to know that Einstein was not satisfied with his theories of relativity, and had already begun his research on a unified field theory. Einstein realized that neither special nor general theory of relativity removed the disturbing dualism of particle and field, that is, both particle and field exist side by side. His life long search for a unified field theory – a generalization of his field equations which would perhaps unify the gravitational and electromagnetic fields – was one of the most remarkable and intellectual projects ever formulated in the history of science. Hermann Weyl also made a serious attempt to develop a unified field theory as early as 1928. It was then extended by Sir Arthur Eddington in 1921. Einstein generalized Eddington's theory, but soon became dissatisfied with it. In 1925, Einstein developed a different version of his unified field theory about which he was most enthusiastic. However, during his twenty-two year stay in Princeton, Einstein constantly strived for development of a unified field theory that would contain a set of equations unifying the phenomena of both gravitation and electromagnetism. The final version of his new theory was published in a series of papers from 1945-1953. In 1953, Einstein published a short note in response to a criticism of the unified field theory.

It is about early 1948 that S.N. Bose renewed his past interest in Einstein's theories of relativity. In a series of seminar lectures organized by his research associates from 1948, Bose himself explained a number of fundamental points concerning weaknesses of the Einstein field theory as well as the Schrödinger (1947-49) unified field equations . As a result of his many years of study, Bose published five papers on various aspects of the unified field theory during 1953-1955, but he achieved no major breakthrough. In fact, Bose sent one of these papers to Einstein in 1953, Einstein wrote him an elaborate letter and, just before closing it, underlined the sentence, "This is to show that equations $\Gamma_i = 0$ do not involve any arbitrary assumption...has furthermore the advantage that it exhibits transposition invariance." Indeed Bose had a number of contributions to the unified field theory including some major changes in the field equations. He obtained the general solution of Einstein's field equations connecting the basic field quantities and affinities in the non-symmetric field theory. His other major results included Bianchi-Bose identities which reduce to Bianchi-Einstein identities, and the settlement of the compatibility issue for the unified field theories. But, according to Einstein, Bose's work broke no new ground on the subject. After 1955, Bose neither published any scientific papers, nor seriously participated in further development of the unified field theory.

3. CONCLUDING REMARKS.

It is hoped that enough has been discussed to give some definite impression of Bose's personal and professional life as well as of the range, power and depth of his unique contributions to modern physics. This article also conveys some of the glamour of modern science and it is also a very human story of a man whose deep commitment to science and society led him to believe progress and prosperity of his motherland would be impossible without science and without the best use of human resources. Throughout his life, Bose was deeply committed to family and friends, social reform, human and world affairs with the preservation of freedom and peace. He also profoundly believed in the spirit of cooperation and love of humanity. By any standard, Bose was a great man.

Bose's whole career was totally dedicated to the pursuit of fundamental scientific discovery, dissemination of scientific knowledge and popularization of its value to common people through their native language. Bose was undoubtedly one of the most brilliant and influential scientists of the twentieth century. He revolutionized physics with his remarkable contributions to quantum statistics. His unique image in the research and teaching of contemporary physical sciences is still extremely predominant. Bose eventually became a celebrity in India, almost as much a household name as Tagore, Gandhi, and one of the legendary figures in the world of science. There is no doubt at all about Bose's profound and everlasting impact on physical science and the scientific community of the world. In many impórtant ways, Bose made a significant and permanent contribution to the welfare of the human race. He will be remembered forever not only for his great scientific achievements, but also for his unique contribution to the welfare of mankind. Today, one hundred years after his birth, we pay tribute to this great man, and at the same time, we can assess and marvel at the magnitude of his outstanding achievements. Any appraisal of S.N. Bose must recognize his greatness both as the man and the scientist of all time.

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