Bose and Einstein: The Case of an Early Indo-German Scientific Cooperation[1]

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Ladies and Gentlemen, dear Colleagues!

I feel very pleased and honored to speak to you on the occasion of the inauguration of the Bose-Einstein Lecture in India. I am very grateful for this opportunity because I firmly believe that the Indo-German Scientific Cooperation is very important and should be given even more attention in the future. Science has been very important in India and also in Germany. It has been carried out in both countries on a high international standard. For this reason scientists in both countries can learn from each other and cooperate for the benefit of both sides. Hence, we should take advantage of any opportunity to make this mutual potential visible to the society and to politics but also to the scientific world in our countries, to stimulate more intensive joint projects and endeavours.

Ambassador Singh Bawa, Ambassador Elbe and Councellor von Welck: I thank you very much for this invitation and even more for your initiative to inaugurate this Indo-German Lecture series and to choose the names of Bose and Einstein as its patrons. Both of them were not only outstanding internationally highly recognized and admired scientists but also personalities which should stimulate talented people like both of them rising from very far below to highest importance and fame. They truly serve as an example of encouragement to all young talented people to pursue their education and scientific endeavour to the best of their talents.

The doors Bose and Einstein have pushed open by molding their knowledge together prevails until today. Bose-Einstein Condensation became a major scientific topic in the last two decades, but its foundation was laid down in the second decade of our century. It is by the way interesting to observe that the communication of scientific ideas and knowledge in the beginning of our century was not too much slower and clearly very profound even then while the internet still had sixty years to become a reality.

Before I will embarge on Bose's and Einstein's scientific work I would like to draw out a short life resumee of the two scientists.

[1] First Bose-Einstein Lecture Delhi, 12.02.1997

Satyendranath Bose was born on January 1, 1894 in Calcutta. He attended the Presidency College of Calcutta from 1909 and received a Bachelor of Science degree in 1913, a Master of Science degree in 1915 at the age of 21. In 1916 he became lecturer at the University College together with Meghnad Saha, an old friend of him already since college times who later became the President of the Indian Institute of Science in Bangalore, an institution which has very close scientific ties to Germany today.

In 1921 Bose was appointed as a reader at the newly founded Dhaka University. His appointment nearly faltered when the university ran out of funds, but at the end Bose could stay there and write his famous paper "Planck's law and the hypothesis of light quanta". It was this paper which started Bose's interaction with Einstein who knew him from literature already quite well because Bose translated into English Einstein's paper on general relativity in 1916 when he was still lecturer at the University College in Calcutta.

The paper, submitted to Einstein was initially sent to the Philosophical Magazine in England. Bose was very confident that it would appear there soon. However, this journal kept silent. Finally Bose went on and sent the paper directly to Albert Einstein with a letter dated the 4th of June 1924. He asked Einstein to accept this paper for publication in Zeitschrift für Physik and did not hesitate to ask him for the translation into German. To Einstein he wrote "because we are all your pupils so profiting only by your teachings and by your writings". On June 15th Bose submitted his second paper "Thermal Eliquibrium in the Radiation Field in the Presence of Matter" to Einstein in the Zeitschrift für Physik.

Einstein understood immediately that Bose's paper was a big progress for the theory of radiation. It was published in the August issue under the title "Planck's Gesetz und die Lichtquantenhypothese" with a note by Einstein at the end "Bose's derivation of Planck's law signifies, in my opinion, an important step forward. The method used here gives also the quantum theory of an ideal gas, as I shall show elsewhere." The next Bose paper was published a month later in the September issue in Zeitschrift für Physik. In order to promote Bose's findings Einstein presented these papers in the Prussian Academy of Sciences on July 10, 1924 and on January 8, 1925. In both cases he extended Bose's method. Einstein's letter to Bose can be seen in this paper as a facsimile.

Dhaka University granted S.N. Bose a leave of absence for two years. In October 1924 he reached Paris and spent a year there with Madame Marie Curie and with Maurice de Broglie.

After a year, on October 8, 1925 Bose arrives in Berlin for a second year abroad and meets Einstein in November. Of course, the atmosphere for science in Berlin at that time was extremely inspiring. Bose writes "I was very friendly with Franck, Einstein, Born, Ewald, Slizard and Mark". At the end of this second year abroad (1926) Bose applies for a professor's post at Dhaka University successfully and was appointed Dean of the Faculty of Science at Dhaka University and full professor. It was only after nearly twenty years and many offers to move from Dhaka elsewhere when Bose returned to Calcutta as a full professor of Physics in 1945. He became President of the Indian Physical Society, President of the National Institute of Sciences, was made Fellow of the Royal Society and a national professor in 1959 and received many honorary degrees thereafter. On February 4, 1974 Bose died in Calcutta, one month after his 80th birthday was celebrated throughout India.

Albert Einstein was born on March 14, 1879 in Ulm, he was fifteen years ahead in age on Bose. His carreer started as an electrical engineer with the diploma of the ETH in Zurich in 1888 and a school teacher diploma in mathematics and physics. From 1902 to 1909 Einstein worked at the Swiss Patent Office where he wrote in 1905 his famous papers on Planck's Law of Radiation, on special relativity, and on the mass energy equivalence. He received a PhD in Zurich in 1905. Seven years later (1912) he published his paper on general relativity. As a consequence of these outstanding achievements Einstein was made professor of physics in Berlin in 1914 and received the Nobel prize in physics in 1921 on the photo effect explained by him on the basis of quantum physics. It was only after this period, while he was already famous for his groundbreaking discoveries, when Bose approached him in 1924. I think it speaks very much for the openness of Einstein that he took the papers from an unknown and fairly younger colleague from as far as Dhaka very serious and immediately paved the way for Bose's success. - As you all know Einstein was forced by the National Socialists in Germany to leave in 1933 for Princeton. He made a scientific home at the Institute for Advanced Study there and died in Princeton on April 18, 1955, 76 years old.

Einstein is a symbol for modern physics. His expulsion in 1933 is also a symbol for the intellectual downfall Germany has experienced in the Third Reich. Einstein's push for the

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development of nuclear weapons must be seen on the background of his experience with the ruthless dictatorship Germany had adopted. Scientists should never forget their responsibility to fight against the repetition of such a regime all over the world.

Clearly, my short review of the lifes of Bose and Einstein is not comprehensive and complete in any respect. But you may understand, how important it was for Bose to get in contact at the right time with such an outstanding scientist in Europe like Einstein where the development of quantum mechanics flowered with several important discoveries each year, and where the total atmosphere was so intriguing and stimulating for S.N. Bose.

But now I have to turn to the physics Bose and Einstein pursued in the papers mentioned already in Bose's curriculum, the scientific case for a different statistic in physics. This originates from the question what energy states particles, for example gas molecules, can occupy at different temperatures.

The first approach to this problem came from Maxwell and Boltzmann. As you can see from the graphic display (see Fig.) for two distinguishable particles x and y there would be four possibilities in the arrangement of them in two different energy states. Both particles could be in the lower state, both particles could be in the upper state, the x could be in the lower state and the y in the upper state, or vice versa the y could be in the lower state and the x in the upper state. Hence, for two distinguishable particles there exist four possibilities. Without proof I mention that for three particles 27 possibilities do exist. This Maxwell Boltzmann distribution describes very well the energy distribution of particles at a given temperature. In connection with photons which are indistinguishable Bose pointed out that only three different possibilities exist. Both photons can occupy the lower state, both photons can be in the upper state or one photon each are populating the upper and the lower state. Consequently for two photons there are three possibilities, for three photons there exist ten. Einstein extended these considerations applied by Bose to photons to other particles as long as they have zero or even spin. In this case it would not be excluded by the Pauli principle that these particles could occupy the same quantum state with all their quantum numbers being equal. However, with Pauli's principle that one quantum state could be occupied only by two particles if they differ in one of their quantum numbers there are two or one possibilities for two particles respectively depending whether they are distinguishable or undistinguishable. This led to the so-called Fermi-Dirac statistic. The particles like electrons with their odd spin of S=1/2 were named by Dirac fermions. Equally the particles with zero or even spin obeyed the

Bose-Einstein statistics and were called bosons after Bose. The picture was now complete. The sum of the bosons and the sum of the fermions constitute the universe!

The facts explained in the paragraph before resulted in a completely different distribution of particles as a function of their energy or the equivalent, the temperature. The Fermi-Dirac statistic at zero absolute temperature is very simple to understand: Each state can only accommodate two particles, the others are stacked from one state to the other until the particles are all accommodated. So the occupation number is two and remains so until it breaks down to zero at the highest energy. In the Bose-Einstein statistic the occupation number follows an exponential law for larger temperatures. In order to clarify the consequences of the new statistic I draw your attention to the two cases which I have depicted for the different statistics. In the Bose-Einstein statistic most of the particles are in the ground state and the others are distributed to higher states exponentially. Only if the temperature approaches zero all particles will be in the lower state. In the Fermi-Dirac statistic if the temperatur is equal to zero all particles are in one particular state (actually two of them in each state) with increasing energy until all the particles occupy a state. With raising temperature this occupation may be softened by the Maxwell-Boltzmann distribution at the edge of the distribution slightly. However, basically the occupation pattern remains the same.

Bose particles, the bosons, occupy the lowest possible state at a temperature of T = 0°K, the zero point of the absolute temperature scale. Already Bose and Einstein suggested, that under these conditions condensation into a single macroscopic state could take place, a Bose-Einstein condensate, as it was called soon after their proposal. Such a condensate, a macroscopic quantum mechanical state, requires not only that all particles are in the lowest single level but also linked together to a common phase, like a freight train, where all the identical lorries have the same direction and velocity, i.e. an identical momentum.

Now you may ask yourself whether the case for the temperature being zero degree Kelvin where all atoms are in the lower state could lead to a condensate, in other words to a macroscopic condensate where all the particles move together. In order to obtain such a condensate an additional condition has to be fulfilled. This condition is called phase coherence. This picture with the five pendulums shows you what I mean. All the pendular move at the same time in the same direction keeping their distance constant. This long phase coherence is equal to a "broken gauge symmetry", the matrix for the occupation number and phases between the particles have diagonal and off diagonal elements the first ones being the occupation numbers and the latter ones the phase between them. These few remarks of course are meant to address the physicists among the audience.

London proposed more than fifty years ago that the presence of superfluidity in liquid ^{4}He at temperatures below $T_c < 2.17$ K at normal pressure of 1 bar is linked with a possible Bose-Einstein condensation. Superfluidity is a phenomenon where a liquid looses friction completely, it can creep through the smallest holes or even flow over the edge of a beaker. Today it is known that only 9 % of the liquid He at T = 0K are in a Bose-Einstein condensate.

It was only in the last ten years that a new chapter in the exciting history of Bose-Einstein-Condensation was written. This had to do with the development of atom traps which were suited to hold larger numbers of atoms in the micro Kelvin (μ^0K) to nano Kelvin (n^0K) range (10^{-6} to 10^{-9} ^{0}K) in a tiny volume. There Bose-Einstein-Condensation was observed for up to 100 % of the interacting particles, for example Cs, Rb or Na atoms. These discoveries are important for the understanding of the interacting bosons but have also a tremendous impact on possible applications like time standards, ultra precise measurements of natural constants and their variation with time and location etc. And the expulsion of atom by atom from a Bose-Einstein condensate in a trap realizes the picture of the forementioned atomic freight train, so to speak, i.e. an atom laser.

Summarizing again it could be said that bound systems with zero or even spin are subject to possible Bose-Einstein condensation. How general this principle is and how much it governs the most modern physics at this time can be seen from the table with bosons under study. Pairs of electrons with spin up and down could form cooper pairs which are considered to be responsable for superconductivity. Equal considerations are true for the bound state of an electron and a proton with opposite spin directions, i.e. the lowest hyperfine structure state in hydrogen or in other atoms where the nuclear spin and the electron spin can form an integer number. Bosons can be also formed between neutrons and protons and of course between quarks and anti-quarks as well- in pion and kaon condensates. Last not least the existence of the x-Boson is proposed as a condensate of the top quark and the anti top quark. These remarks should be only a demonstration that bosons and Bose-Einstein condensates are key elements in the most modern theories in physics.

Bose and Einstein - an example for an Indo-German scientific cooperation of fundamental impact. Why did this joint effort take place in such a successful way? Because all the necessary ingredients were there at the right moment! The right passion for the understanding of nature, a common language (English and Mathematics), the freedom to pursue the research to be considered leading to progress in the future not influenced by narrow minded funding agencies aiming for short breathed technology transfer. Eighty years have passed by since Bose submitted his papers to Einstein. And only now applications emerge from Bose-Einstein condensates which may lead to an unprecedented precision in metrology, that enables us to ask questions and answer them e.g. on the origin of the universe, its development as a function of time, on the forces holding it together, and on the basic constituents of matter. In this way, the amalgamation of the ideas of Bose and Einstein can be understood as a crucial tool for the noblest obligation of all scientists: To search for the ultimate truth.

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