appeared on 9th Jan 2013

S N Bose and the Higgs particle

S N Bose laid one of the cornerstones of conemporary physics, says S.Ananthanaryanan.

The coining and the use of the word, '***Boson***', is not a case of honouring a scientist by naming something after him but is active description of a class of particles that behave in a way that was worked out for that class by S N Bose. S N Bose has thus been immortalized in a basic way, which may not be the case with any other scientist.

S N Bose' classic work was a 4 page paper he forwarded to Albert Einstein, with this letter: "*I have ventured to send you the accompanying article for your perusal and opinion. You will see that I have tried to deduce the coefficients ………in Planck's Law independent of classical electrodynamcs*."

The context was the infancy of quantum mechanics, Max Planck's idea of 'quanta' or discrete steps being the rule in nature, rather than smooth and continuous progress, which he proposed to explain the manner of radiation from warm objects. On of the problems that troubled physicists of the turn of the 19th century was the distribution of frequencies at which an object radiated heat. While an object radiated at a range of frequencies, the radiation was the maximum at one frequency and this peak radiation frequency increased as the body grew hotter. The problem was to find a theoretical basis for this observed behaviour. The laws of motion, optics, electricity and the gas laws had fallen into neat, mathematical formulation. While some troublesome things had been discovered, like radioactivity and atomic structure, 'black body' radiation, or the radiation from a non-reflecting surface, also seemed to be within reach of existing knowledge.

Planck and Einstein

The approach was to treat radiating objects as an assembly of oscillators, or vibrating systems, that gave off electromagnetic radiation. A warmer object would have things vibrating more vigorously and more radiation should come at higher frequencies. Given an object at a certain temperature, there would be a distribution of the frequency of vibration of its parts and hence of the frequency of radiation. This kind of thinking had led to a few 'laws of radiation', the Wien's Law, the Raleigh's Law and the Raleigh-Jeans' Law, which gave good fit with experiment for a part of the spectrum, but went off the mark at the extremes. Plank broke from tradition by proposing that the oscillators could not vibrate, and hence radiate, at all frequencies in range, but only at frequencies that changed in 'steps' or 'quanta'. With this basic change, Planck was able to rework existing formulae to exactly describe the radiation spectra of warm objects.

Albert Einstein made a refinement. – rather than consider that the oscillators vibrated at frequencies that changed in steps, he proposed that it was the energy of radiation that had to be in packets, or quanta. Einstein then considered the quanta of energy being emitted and absorbed by the walls of a cavity like the molecules of a gas in a container and used statistical methods, which are effective with gases, to arrive, with the help of Wien's Law, at the same formula for radiation as Max Planck!

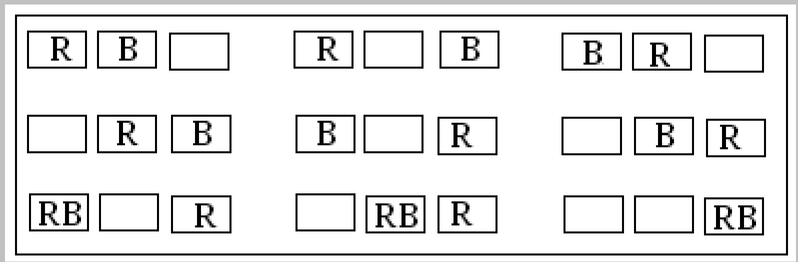
In the case of a gas, the millions of molecules of the gas share the total energy. In principle, this could happen in many ways – with a few molecules being feverishly fast while the rest, which had to manage with the remaining energy, being sluggish. Or there could be a few very slow ones, which forced the others to be faster, or there could be ways that were in between. When a small number of molecules share large or low energy, the different ways that this is possible is the number of ways this small number of molecules can be selected from the total. But when energy is more evenly distributed, this can be done in the number of ways larger groups can be selected and this number itself becomes very large. For instance, if there are 1,000 molecules and 1 molecule is to be chosen, there are 1,000 ways of doing this. But if 2 molecules are to be chosen, then there are 999 ways to choose the second molecule for every way the first molecule is chosen – or 999 x 1,000 = 9,99,000 ways (and divided by 2, as the pairs would be repeated).And if 3 molecules are to be chosen, there are 9,99,000 x 998 ways (divided by 6, to take care of repetitions).It can be worked out that the number of ways that half the number of molecules can be selected is astronomically large.

With billions of molecules of gas, there is such an overwhelmingly larger number of ways that molecules could have ‘about the average’ energy that we end up with the uniform, even temperature, behaviour of a real gas. Einstein had used similar consideration of photons in a cavity, with the help of Wien’s Law, to arrive at Planck’s formula.

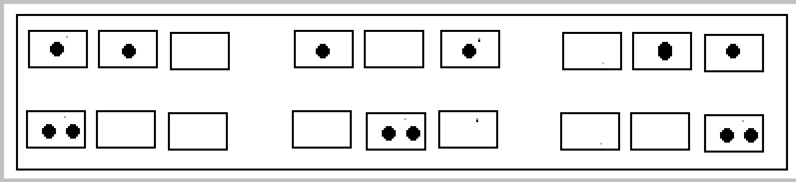
S N Bose

Bose thought the induction of Wein’s law, which was a formula to fit experiment, was ‘contrived’. As there was use of Wein’s law, the final result was not a natural consequence of photons being considered to behave like a gas. And Bose was able to see that there was, in fact, a relevant difference between photons and the molecules of a gas! In the case of molecules, it was, in principle, possible to distinguish each one and count each distribution which had the same energy as a separate instance. But in the case of photons, which were freely absorbed and emitted, there was no way to tell one from another. And another thing was that the total number of molecules was fixed, but not of photons!

The recognition that photons are indistinguishable, or ***identical***, makes an immediate and vital difference. Let us take an example of a red ball and a green ball, being distributed in 3 compartments. This is possible in 9 ways, like this:



But if the balls were of the same colour, then the 1st and 3rd, 2nd and 5th and 4th and 6th distributions become the same and we are left with only 6 distinct distributions, like this:



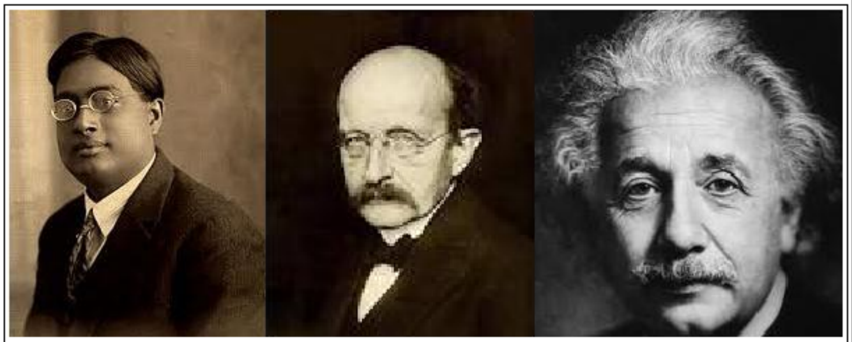
If we consider the balls to be molecules or the photons and the boxes to be the different energies, then we see that there is a difference between the number of possibilities in the case of distinguishable molecules and indistinguishable photons. And when Bose took this into account and also that the number of photons was not fixed and again, that they could come in 2 states of polarization, he was able to arrive at Planck's formula without reliance on any external inputs at all!

BE Statistics

Einstein was quick to realize that his young Indian correspondent had made a landmark discovery and Einstein himself translated the paper into German and had it published, with his own comments, in the journal, ***Zeitschrift fur Physik***. Einstein then wrote a sequel and followed up with work that established the distinction between 'identical' particles and other particles, and the behavior of identical particles, now known as 'Bose-Einstein statistics', as central to many problems in physics.

Physics has come a long way since 1924 when S N Base, 30 yrs of age and a reader in Dhakka University sent that letter to Einstein. The whole category of subatomic particles with the property of 'spin' described in whole numbers, which are allowed to share an energy state, are the Bosons, and the other category, with 'spin' measured in halves, like 1 / 2or 3 / 2, and have to occupy separate energy states, are known as 'Fermions' named after the Italian, Enrico Fermi. The fact that Bosons can occupy the same state, in quantum mechanics makes possible conditions where the molecules in a mass of fluid move 'in coherence' and without resistance, as a ***superfluid***. Or where electrons, which are Ferrmions, form pairs, to become Bosons and flow as an electric current without resistance, in a ***superconductor***.

It has also been found that it is exchange of virtual particles that bring about the forces between things. Thus photons are involved in electromagnetic forces while particles known as 'z' or 'w' are associated with other nuclear interactions. The property of mass itself is explained with the help of the Higgs particles. These particles are all 'whole number spin' particles and belong to the group of Bosons, like the ***Higgs Boson***.



Satyendra Nath Bose Max Planck Albert Einstein