Bose and the Higgs particle

Satyendra Nath Bose laid one of the cornerstones of contemporary physics, says s ananthanarayanan

THE coining and use of the word "Boson" is not a case of honouring a scientist by naming something after him but is an active description of a class of particles that behaves in a way that was worked out for that class by Satyendra Nath Bose. He has thus been immortalised in a basic way, which may not be the case with any other scientist.

Bose's classic work was a four-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."

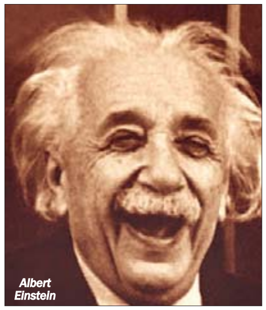
The context was the infancy of quantum mechanics, Max Planck's idea of "quanta" or discrete steps being the rule in nature, rather than smooth and continuous progress, which he proposed to explain the manner of radiation from warm objects. One of the problems that troubled physicists of the turn of the 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.

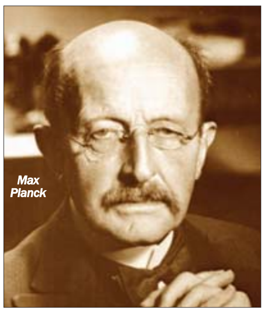
Planck and Einstein

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" — Wien's Law, Raleigh's Law and Raleigh-Jeans' Law – that gave a good fit with experiments 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. He 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!



Albert Einstein



Max Planck

In the case of a gas, its millions of molecules 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 one molecule is to be chosen, there are 1,000 ways of doing this. But if two 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 two, as the pairs would be repeated). And if three molecules are to be chosen, there are 9,99,000 x 998 ways (divided by six, 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 a similar consideration of photons in a cavity, with the help of Wien's Law, to arrive at Planck's formula.

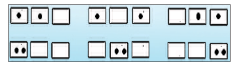
SN Bose

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 that 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 three compartments. This is possible in nine ways, like this:

But if the balls were of the same colour, then the first and third, second and fifth and fourth and sixth distributions become the same and we are left with only six 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 two states of polarisation, he was able to arrive at Planck's formula without reliance on any external inputs at all!

Satyendra Nath Bose

BE statistics

Einstein was quick to realise 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*. He then wrote a sequel and followed up with work that established the distinction between "identical" particles and other particles, and the behaviour 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 Bose, 30 years old and a reader at Dacca 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 one/two or three/two, 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 the 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*.

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Trade muddle

latha jishnu **wonders if Geographical Indications are safeguarding the interests of growers and artisans**

THE people of Hoovina Hadagali (population 27,958), the *taluka* headquarters of Karnataka's Bellary district, are inordinately proud of their variety of *mallige* (jasmine). So are the growers of Udipi and Mysore, all of them claiming unique and distinctive features for their varieties of these sweet-smelling flowers that are offered to temple deities or used by south Indian women to adorn their hair. Jasmine abounds in India but the flower-growers in these towns have secured their varieties with the Geographical Indication tag. It is all part of the GI craze that has been sweeping India ever since the authorities began popularising it about a decade ago after it became a hot issue at the World trade Organisation.

GI is an Intellectual Property Right that is granted to a product because of its geographical uniqueness and is aimed at protecting and expanding markets. It is a community-shared benefit that is not available to individuals or business enterprises. Invariably, GI products carry the name of the place from where they originate because agricultural items in particular have qualities that derive from their place of production and are influenced by local factors, such as climate and soil. Since GIs are primarily a global trade issue, one wonders why a tiny group of flower-growers should want this tag.

Do the jasmine-growers of Hoovina Hadagali foresee rivals violating their right, if not globally then locally? Do they, perhaps, worry that lesser jasmine from other parts of Karnataka will be passed off as Hadagali *mallige*?

The GI craze in India is as inexplicable as the ways in which the Geographical Indications Registry in Chennai grants it. Since April 2004 the registry has handed out 178 GIs, raising questions about its rationale and methodology and leading to controversies that have seen legal challenges to some of them. To stay with the jasmine example, do the growers of Hadagali or Mysore or Udipi, for that matter, sell their prized flowers as a branded product?

Reflective of the lack of clarity at the Chennai registry is the case of the Payyanur Pavithra Mothiram or "Payyanur's pure ring", whose GI was revoked last month by the Intellectual Property Appellate Board. This gold and silver ring with a distinctive design is made in the eponymous village of Payyanur in Kerala's Kannur district and was earlier worn by temple priests during the performance of rites. But gradually it was commercialised as an ornament bestowing spiritual power and material wealth on the wearer and thus found a thriving market. There are dozens of jewellers who claim to make the "original" ring. It was the filing of a challenge in Madras High Court and subsequently at the Ipab by a jeweller that led to revocation of the GI granted in 2009.

Hopefully, this will make the GI Registry take a harder look at the huge list of pending applications — and on the long-pending rectification petition on the GI for Darjeeling tea.

CSE/Down To Earth Feature Service

The curious world of the ice-crystal experts

While most everyone might like snow, not many are obsessed like the scientists who study these icy enigmas. nicola gill **enters the curious world of 'dendrites' and 'plates'**

DR Chris Westbrook works in deepest Hampshire at the Chilbolton Observatory, home to the world's largest steerable radar dish, at a whopping 25 metres across. Inside, lights blink and instruments receive continuous feedback from the giant dish pointed skywards and looming ever-present outside the window. But even on the hottest summer day, he is buried deep in snowflakes. "The radar dish sends out microwave pulses into ice clouds high up in the atmosphere where the temperature is always well below freezing – whatever it is down here," he says. The ice crystals, nestling in the ice clouds as unborn snowflakes, bounce those microwaves back and the echoes which return are pored over and analysed by Dr Westbrook and his team.

"We have the most sensitive equipment for studying ice clouds in the world," he says. Westbrook is one of just a tiny handful of snowflake researchers in the world, a group of obsessives who live and breathe snow – fixated on chasing the perfect flake and understanding exactly which weather conditions will produce the many different formations. "It may seem slightly odd that I've devoted myself to studying snowflakes when the UK isn't renowned as an especially snowy place," he continues, "but, in fact, the vast majority of precipitation in this country starts as snow, which melts high above us and then falls as rain, which we certainly do have a lot of. So if you want to predict precipitation you need to study snow and how it forms."

So far, so dispassionate; ask Dr Westbrook if he likes making snowmen and he rather frostily replies that he's as keen as the next man ("but I have a degree in physics and electrical engineering and where others see a winter wonderland I see physics in action"). But ask him about the way snowflakes are formed and fall to earth and the amazed child inside emerges as he describes the physics-meets-fairytale element of his work.

"The aerodynamics of snowflakes have an inherently mysterious quality we've yet to crack," he enthuses."We classify their falling style in four unique ways: the 'tumble' is a sort of head-over-heels action, the 'spin' is a vertical downwards motion with a built-in rotation, the 'pitch and glide' is best described as a zig-zag and the 'twirl' is how we describe a snowflake that's descending while spinning and rotating at an angle. Which they do depends on how fast they fall and their size, but it's a puzzle that's not solved and we don't know why they behave as they do all of the time. As for the intricate formations of individual flakes, I defy anyone not to be amazed."

Of course, it's those spectacular shapes – some like icy fireworks caught mid-explosion, others frozen, fantastical many-armed sea creatures – that fascinate the rest of us non-scientists. Nearly all snowflakes (or snow crystals, as scientists insist on calling them, as a large flake can actually be made up of several crystals that clump together on their drift earthwards) have six-sided symmetry, though three- or 12-sided crystals also fall. You will never see a snow crystal with four, five or eight sides. It was ancient Chinese scholars who first noted their sixfold symmetry and they made beautiful complex categories and charts detailing their infinite variety and grouping them into types; as no two snowflakes can ever be identical.

Broadly speaking (there are several competing classification systems), the classic, celebrated Christmas-card snowflake is categorised as a dendrite (meaning tree-like, with branches and side-branches). These are the iconic superstars of the snowflake world, hogging all the glory and most of the photo opportunities. They can be subcategorised as stellar, radiating or fern-like. As if winning the beauty contest weren't enough, dendrites' supermodel qualities (they can be extremely thin and light) also mean they make the best powder snow for skiing.

Next in line, the supporting cast, are the plates (stellar, sectored or split) with 12-sided flakes bringing up the rear. The ugly sisters, which in reality make up the vast majority of snowflakes, are the rather dull, hollow and capped columns, needles, simple prisms, bullet rosettes and asymmetrical specks, doomed forever to be the boring, bitty, non-showbiz flakes we brush off our sleeves with nary an "ooh" or an "aah".

The categorisation of snowflakes has a long history.

Chris Westbrook

In 1655, Robert Hooke published a large volume called *Micrographia*, containing his sketches of snowflakes viewed for the first time under the new invention of the day, the microscope. American farmer Wilson "Snowflake" Bentley, devoted most of his life to capturing images of snow crystals and his famous book of that name is still in print to this day. Japanese physicist Ukichiro Nakaya created the first truly systemic classification scheme for snowflakes in 1934, in which he subdivided falling flakes into 41 individual types which meteorologists Magono and Lee almost doubled by producing a chart of 80 different types in 1966. Mathematician and philosopher René Descartes is one of many fine minds through the ages to be fascinated by snowflakes and to ponder how such perfection could be created.

While every flake really is a law unto itself, other supposed snow "facts" are not quite so true. The oft-quoted idea that it's "too cold to snow" is nonsense (it snows at the South Pole where it's rarely above -40 Celsius), and even the apparent truism that snow is white turns out to be slushy logic. Ice crystals are clear, like glass, but when they form a large pile, light is reflected off the surface, bounces around and eventually scatters back out. Since all colours are scattered roughly equally, snow only appears to be white.

These, and many other reasons, are why world-renowned snowflake obsessive, California-based Ken Libbrecht has made it his life's work to study, photograph and "grow" snowflakes. The author of several beautiful books showcasing his favourite flakes out of the 7,000 he has photographed, he lives and breathes dendrites, rosettes and plates. "There is something magical about snowflakes," he says from his laboratory in Pasadena. "You don't often see such complex symmetry in nature and that makes them extraordinary. The whole intriguing structure of a snow crystal simply arises quite literally out of thin air, as it tumbles through the clouds. The way the crystal grows depends on the temperature it is shaped in – a simple enough idea to grasp – but the underlying physics is fiendishly complicated and has remained a puzzle. I spend a lot, and I mean a lot, of time thinking about this."

As Libbrecht explains, the life of a snowflake is a hidden, epic, scientific journey in which it transforms through liquid, gas and solid states. "Snowflakes begin life as water vapour in the air – evaporated from oceans, plants, even your breath – and when air cools down at some point the water vapour will condense out. Near the ground it could, for example, be as dew, but higher up it condenses on to airborne dust particles into countless minute droplets. A cloud is just a huge collection of these water droplets suspended in the atmosphere."

The next stage is where it gets exciting, say Libbrecht. Depending on conditions, these droplets could fall as dreary rain, sleet or hail, or descend as mist or fog. But when conditions are right, the alchemy occurs and these minute droplets metamorphise into something more impressive. "At around -10° Celsius, the droplets gradually freeze into minuscule particles of ice," he says. "When humidity is high enough, water vapour condenses on to its surface, gradually building a snowflake. At first they are very small and mostly in the form of simple, hexagonal prisms – but as they grow, the branches sprout from the corners to make ever more complicated shapes."

By growing crystals in his lab, Libbrecht has learnt how the multitudes of varying shapes depend almost entirely on the temperature and humidity. For example, thin plates and stars grow around -2° Celsius, while columns and slender needles appear near -5° Celsius. Plates and stars form around -15° Celsius and a combination of plates and columns are made at around -30° Celsius.

His devotion to dendrites has led him halfway around the world and he thinks nothing of basing holidays with his wife and two children exclusively around snowflake sightseeing. On one trip, he took his young children to Japan, where snowflakes are virtually a national craze. "Snow-crystal tourist spots are popular with the Japanese and I flew my family over."

The Independent, London