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SYMMETRY BREAKING, THE HIGGS BOSON & ABDUS SALAM

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Over the past two years, the Higgs Boson has seeped into the popular consciousness, and with the announcement of this year's Nobel Prize, it is in the limelight once again. Yet, many people are still not quite sure what this particle is, and what, if anything, it has to do with Pakistan's only Laureate, Abdus Salam.

The 2013 Nobel Prize for Physics recognized a mechanism whereby the breaking of symmetry causes a field to pervade the vacuum. To get a sense of what that means, think of the vacuum as the blank canvas upon which our universe is painted, and the Higgs field as a color wash covering the canvas. Had the canvas been pure white, the 'true' colors of our painting would show up; instead, we experience colors after they have been tinted by the background - the Higgs field taints our perception. Just because the canvas is blank doesn't mean there's nothing on it!

Vast ideas have many sides, and often, a different metaphor is needed to explain each facet. One catch phrase regarding the Higgs Boson is that it explains the origin of mass. To understand the connection, consider how we experience mass. When asked to judge how heavy something is, an instinctive reaction is to try pushing the object in question. Intuition tells us that if the same force is exerted on two objects, the heavier one moves slower than the lighter. If two balls, pushed with equal force across a flat surface move with the same speed, we conclude their masses are equal.

But what if the balls carry electric charge, and we perform this experiment in the background of a constant electric field? We might find one ball moves slower than the other, and mistakenly conclude that it is heavier, whereas in truth the masses of both are the same. The discrepancy arises because first ball is pushed in a direction where its motion is resisted by the field, whereas the second ball is pushed in an unaffected direction, and so, proceeds at its natural speed.

In a symmetric universe no direction would be singled out, and regardless of its orientation, very ball would whizz around equally fast. If, however, we introduce a field that violates symmetry, we can pick out a 'special' direction, along which balls will move slower, and hence, appear more massive.

Just as an electric field can be oriented along any axis, the Higgs field too, is free to choose a direction. An illustrative example is that of a marble in a Mexican hat. Poised on the hump of the sombrero, the marble is surrounded with infinite possibilities, each as good as the next, but its position is precarious and almost impossible to maintain. Sooner or later, it will roll down into the circular rim, spontaneously breaking the symmetry. The direction in which the marble falls is completely random; the point on the rim where it lands is not distinguished in any way, until by virtue of the marble landing, it becomes the point of reference for everything that happens from then on.

Mass, which we had thought of as an intrinsic attribute, turns out to be a perceived quantity, a manifestation of the interaction between an object and the background. Particles which appear identical in the absence of a field can take on a variety of appearances in its presence.

In 1964, Higgs, Brout & Englert, and Guralnik, Hagen & Kibble, had (independently) concluded that a vacuum does not necessarily connote the absence of everything, but could in fact be suffused with a field, which explicitly breaks symmetry. While this mechanism was used in subsequent theories, it was hard to prove explicitly. Think back to the color wash on the canvas. If something is everywhere, if it pervades space and forms the background for all we perceive, how do we convince ourselves it is really there? The detection of the Higgs Boson at CERN last year was hailed with such excitement because it provided long sought evidence for the existence of the Higgs field, and - almost fifty years later - the theory of the interplay between symmetry breaking and mass, was finally lauded with the Nobel Prize.

What does any of this have to do with Abdus Salam? In 1979, Sheldon Glashow, Abdus Salam and Steven Weinberg were awarded the Nobel Prize for showing that the familiar electromagnetic force, and the relatively newly discovered weak nuclear force (responsible for radioactivity, among other things) were in fact the same fundamental force in different guises. The claim was truly audacious. There were many glaring distinctions between the two forces; for starters, unlike electromagnetism, the weak force is alchemical and can transform one particle into another; but even more problematic was the discrepancy in their ranges. Electromagnetic attraction and repulsion is felt across large distances, whereas the weak force dies out at nuclear scales.

It was already known that forces are transported across space by particles; the carriers of each force have certain unique characteristics, in keeping with their 'message'. The electromagnetic force can travels across large distances, at the speed of light, because its force-carrier, the photon, is massless. The weak force only survives subatomic distances because its force carriers (called the W-, W+ and Z bosons) are very heavy.

The weak and electromagnetic forces could only be tied together if their force carriers were united. This is when Glashow, Salam and Weinberg used the model created by Higgs and others. The apparent imbalance in mass was not an intrinsic feature of the force carriers, they said, but the manifestation of a broken symmetry. When the Universe was just born, perfect symmetry prevailed and the W+, W-, Z and the photon were indistinguishable. With the passage of time, asymmetries developed spontaneously and the vacuum was pervaded with a Higgs field. As a result of their various interactions with the Higgs field, three of these particles acquired masses, while one remained massless. Consequently, their apparent behavior diverged so much that the forces they carried began to seem completely different.

Abdus Salam used the following analogy to explain: look at ice and water', he wrote.

'They can co-exist at zero degrees Centigrade, although they are very distinct with different properties. However, if you increase the temperature you find that they represent the same fundamental reality, the same fluid. Similarly, we thought that if you could conceive of a Universe which was very, very hot ... then it was our contention that the weak nuclear force would exhibit the same long-range character as the electromagnetic force. You would then see the unification of these two forces perfectly clearly.' Since we only experience these forces as they are now and not as they were in millennia past, we perceive electromagnetism as being very different to the weak force, whereas in fact the two can be traced back to the same root.

Perfect symmetry is aesthetically appealing, but sterile in practice. Only by breaking the symmetry of the early universe do the fundamental forces take on their unique guises, causing matter to coalesce, and form elementary particles, which congeal into atoms that dance around each other, and give rise to our vast and varied world.

There is a huge difference between breaking a symmetry, and not having one at all; in both cases, the end result may look the case, but in the former scenario, there is an underlying simplicity of design, and in the latter, there is no pattern to guide us. Our universe could have preserved symmetry, in which case we would all be frozen in stagnant perfection; or it could have had nothing to do with symmetry, in which case we would be surrounded by chaos. Instead, we find ourselves in an ideal situation where the equations that describe our universe are symmetric, but the solutions are not. As a result, Nature can exhibit immeasurably rich structures while still being economical in essence, and we can make sense of the wild and wonderful phenomena that surround us, by appealing to just a few guiding principles.

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