Roughly one page essay: Nambu-Goldstone modes, beyond theory.[a)]

J. S. de Boer[1, b)]
Lorentz Institute for Theoretical Physics

(Dated: February 13, 2018)

The lecture introduced the Goldstone theorem and the Nambu-Goldstone modes. However, it did not touch upon the usefulness of this particular theorem, which warranted investigation. In this roughly one page essay, we get lost on the electronic information landscape to find motivation for teaching the Goldstone theorem. And we do find it, in a glorious additional global field that couples to force particles in a manner that lets them acquire mass and is separately quantised giving rise to a Big Thing.

The goldstone theorem describes a generic feature of spontaneously broken symmetries giving rise to excitations whose energy tends to zero for very large wavelengths λ. Technically, whenever a quantum system spontaneously breaks a continuous symmetry without long-range interaction between its constituents, then bosonic excitations with dispersion $\hbar\omega(\kappa)$ that go to zero for $\kappa = \frac{2\pi}{\lambda} \rightarrow 0$ must emerge. The latter are known as Nambu-Goldstone modes. Conceptually, the $\kappa \rightarrow 0$ limit corresponds to very softly pushing the material. This gives rise to a collective response at zero energy, which implies a collective displacement. In other words, you just move the entire material. This linear response is called *rigid*, a notion that is generalised for such responses even if they do not correspond to physical movement without compression.

I. A QUICK SURVEY

A quick investigation of the Goldstone mode does of course lead us to wikipedia[1]. They list a number of natural examples of goldstone modes, namely phonons, magnons, pions (pseudo-Goldstone bosons) and even longitudinal polarization components of W and Z bosons that are not observable. In this final case an inkling is given of the future lectures, because they mention these three would-be W and Z bosons are "eaten" by the three gauge bosons that correspond to the three broken generations. This is apparently described by the Higgs mechanism, which we will talk about in future lectures.

II. THE GOLDSTONE THEOREM FOR DUMMIES

I ran into this nice blog[2] by Dr. Tomasso Dorigo, an experimental particle physicist. The first thing he notes is that the Goldstone's theorem is a crucial preliminary to understand the need for a Higgs boson in the Standard Model. The Higgs boson was discovered in 2012 which I would say makes it extra interesting.

At the end of the post, he transmutes the inkling of future lectures into an essential motivation for the Goldstone Mode. To quote:

> Massless scalar particles do not belong to any reasonable theory of nature. Our world would be a quite different place if there were massless scalars around! We do not observe such particles. Indeed, there is a mathematical trick, called the Higgs mechanism, which gets rid of the massless goldstone bosons. The degrees of freedom of the theory associated to the Goldstone bosons reappear as mass terms for the weak vector bosons... But this is stuff for another lesson.

III. HIGGS MECHANISM

Of course, I can't help myself and ran to Wikipedia[3] again. The Higgs mechanism is essential tot he standard model, explaining the generation mechanism of the property called mass for gauge bosons. Without the Higgs mechanism all bosons would be considered massless, which is problematic because measurements show they do possess mass. Spontaneous symmetry breaking triggers the Higgs mechanism, which in its simplest description adds a quantum field (the Higgs field) that permeates all of space.

For the rest of this dive into future lectures, we must wonder who ate the Higgs[4]? The Goldstone modes of the spontaneously broken Higgs field are "eaten" by force particles (Bosons) such that they acquire mass.

[a)] Footnote to title of article.
[b)] Electronic mail: deboer@lorentz.leidenuniv.nl

IV. CONCLUSION

There is a very good motivation for teaching the Goldstone theorem in this course. This was of course expected, but it is valuable to consider just why it is worthwhile. A recent but ill understood "Big Thing" discovered in Physics, in our lifetimes, is the Higgs boson. At the end of this course we will apparently have a handle on what was discovered.

Already, some explanation can be given. The Higgs mechanism requires a permeating field that has Nambu-Goldstone modes. Apparently, through some interaction these are created/annihilated in a manner that lets force particles acquire a mass term. Yet additionally, there is nothing to stop us from quantising the Higgs field and acquiring particles - Higgs bosons - from that quantisation.

REFERENCES

[1]https://en.wikipedia.org/wiki/Goldstone_boson.
[2]https://dorigo.wordpress.com/2007/11/10/the-goldstone-theorem-for-real-dummies/.
[3]https://en.wikipedia.org/wiki/Higgs_mechanism.
[4]https://www.quantumdiaries.org/2011/10/10/who-ate-the-higgs/.