The non-emptiness of the vacuum

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Every time we talk about vacuum, an empty place immediately comes to our mind. A place that has absolutely nothing. However, we must be completely surprised to know that in modern physics the concept of vacuum space is not an empty place! To understand this "kind of contradiction" we must understand that from the most fundamental point of view, the universe is not made of particles, but of fields.

From the physical point of view, a field represents the distribution of some physical magnitude in the space-time. That is, once we have some physical magnitude, its corresponding field appears. It is possible to measure that field and it has the property to "inform" of the existence of such magnitude and to carry all important physical quantities, such as linear momentum, angular momentum, energy and so on.

From the mathematical point of view, a field is a function from the space-time. The most famous example is the Electromagnetic Field. AT THE MACROSCOPIC SCALE, this field is completely described if we specify at each point of the space three values for the Electric Field **E** and another three for the Magnetic Field **B**. Thanks to a mathematical theorem, we can only specify four values for the Electromagnetic Potential **A**, and then we can construct the Electric and Magnetic Fields from it.

We can expect that these values will depend on the fact whether we have a magnet or objects with electric charge, but a very important fact is to understand that even in a region placed far from any object, the Electromagnetic Field *continues there*! The value of its Electromagnetic Potential is zero in any place of such region. The Field is then "off" but still present!

Each field occupies all corners of space – always. We can see it as some kind of "gelatin" scattered by the whole universe, which is without deformation when the field is off, but it is distorted in a greater or lesser way as soon as the field takes larger or smaller values. Of course, all the different fields can coexist together, so any one of them can be manifested as soon as it starts to take any value.

A field is associated to all elemental particles. Besides the Electromagnetic Field that it is associated to the Photon (the elemental particle of light), there exists an associated field to each elementary particle that we know: there exists the Field of the Electron, the Field of each one of the six Quarks (Up, Down, Strange, Charm, Top and Bottom), the Field of the Gluon, the Field of the Higgs and so on… At this point, it is easy to understand why the physical space-time is never empty: it always has all these fields. Even if they are off, they are always there! A set of non-deformed gelatin!

AT THE MICROSCOPIC SCALE, the situation becomes more interesting! This happens because we must keep in mind the quantum physics rules; these allow that each field be "undecided" in reference to the value that it has at each place: it can take a value of 1.3 in some place, for example, 0.45 in a second place, and 2.7 in another place (we are using here just one number to specify a Field in each place, however, most of the Fields need more than one number). So, to specify, for each Quantum Field we must to give some probability to each possible value… in each place. It is necessary to comment that in physics the phrase “microscopic scale” means at the level of the atom, and not as the biological meaning for the microscopic scale: microbes.

The key idea at this point is that what we call “vacuum” is a situation where all the quantum fields have THE LOWEST POSSIBLE ENERGY and that situation does not mean that all the Fields have exactly a zero value at any place, but that the Fields are “undecided” in some specific way. This fact gives support to the idea of the non-emptiness of the vacuum: the Space has a lot of different Fields, and those Fields are not off – they have some probability to get values different from zero and it is in average that they are zero. The trend of the Fields to have some deviations from zero, that is, the tendency of that “gelatin” to have some deformations, is known as quantum fluctuations.

The Fields can be coupled! That is, these different “gelatins” are glued between them in a stronger or weaker way, and in such a way that the deformations in one of them can have an effect on others. If we consider Fields that are only weakly affected between them, that is, *weakly coupled Fields* as the Electromagnetic Field and the Field of the Electron, we will find deformations that will appear as a consequence. In our case, the picture that we have from quantum fluctuations makes us see the “vacuum space” as a place where all the time particles and antiparticles (in our example, a sparkling soup of Electrons, Positrons and Photons…) are appearing and disappearing; this means that the Fields in the vacuum always have some activity.

There are also strongly coupled Fields, as the Fields of the Quarks and the Field of the Gluon, but the situation where they have the lowest possible energy is very complicated (in fact… it is unknown how to make those calculations!). We can find the quantum fluctuation of these Fields in the vacuum with the help of a supercomputer; we can say in short that even when that Fields are zero in average, the combinations as Gluon on Square (Gluon-Gluon) or Quark on Square (Quark-Quark) are not zero in average. The Space is also full of these gelatins in a very particular way (these effects are known as the “Gluon Condensate” and “Quark Condensate” or “Chiral Condensate”).

That is, if the Space was made only of particles, the vacuum space would be just a place where there are no particles and, by consequence, nothing. However, as the Space is made of Fields, the “Vacuum Space” is a very interesting place! Even more so, our own existence depends directly on its properties: the mass of the Electrons that make us arises from the interaction of them with the average value of the Field of the Higgs and the mass of our Protons and Neutrons (they are more than 99.9% of the total mass of our body) exists thanks to the complexity of the vacuum of the Gluon and Quark Condensate…. So, we are really fortunate that there is non-emptiness of the vacuum!