Dynamics of cosmological domain walls in the Standard Model and its simple extensions

Description for the general public

Names such as a spontaneous symmetry breaking or domain walls, may seem at first sight totally exotic. However everybody met in everyday life with items, which principle of operation is based on the phenomenon of the spontaneous symmetry breaking which leads to the formation of domain walls. These objects are magnets.

Magnets which we use normally are made from different materials, however the thing which distinguish them is their magnetic properties — they are ferromagnetic. Let us image that we have some magnet or even better let it be spherical. It is known sphere looks the same independently how it is rotated or in other words sphere has rotational symmetry. We can roll it on the desktop in front of us and we will not recognize if we even rotated it. Let us take second magnet. If we put it enough close to the ferromagnetic sphere, the sphere will rotate. If we put the sticker on it at the point closes to the second magnet and we repeat the experiment again, the sphere will rotate and the sticker will be closest to the second magnet again. As long as for us the orientation of the sphere does not matter, the magnetic interaction is sensitive to it. The considered ferromagnetic sphere, as any magnet, has distinguished north and south poles which determine a direction in space (let us say north-south direction). Physicists in such a case say that the rotational symmetry of sphere was broken by its magnetic interaction.

Moreover, if we perform similar experiment in temperature higher than the certain temperature (called Curie temperature), given for each ferromagnetic material, then the situation will change and the sphere will not rotate. Is such high temperatures ferromagnetic materials lost their properties and the rotational symmetry is restored. what is even more interesting, if we will cool down the sphere and perform our experiment, then the sphere will still not rotate, even through it will be attracted to the second magnet. in order to explain why is this we need to perform more complicated experiment.

If we cut through the chilled sphere and examine it through a magnetic force microscope (the version of atomic force microscope sensitive to magnetic interactions), we will found regions with determined directions of magnetic field which are called domain walls. Because orientations in neighboring domains are not the same, between them we will see transitional regions that is domain walls.

All experimental data indicate that the Universe has been expanding and cooling down in the past. This means that the Universe was very hot in the past. Thus with the evolution of the Universe, symmetries of the elementary particles physics which was unbroken in high temperature, could be broken during the cooling down. Such situation may had took place in the early Universe in the case of electroweak symmetry, connected with electromagnetic and weak interactions.

electroweak symmetry is broken by the Higgs field (as rotational symmetry is broken in previous case by magnetic field) which existence was validated by the discovery of its quanta that is Higgs boson, in 2012. We know now, due to measurement of the Higgs boson mass, that there are two possible (with assumption of the validity of the standard Model up to high energy scales) patterns of the electroweak symmetry breaking. Only one of them corresponds to observed masses of W and Z gauge boson, however both of them might be realized in separated domains in very early Universe. The aim of the project is to explain how this situation could be realized in the past and, foremost, how formed in this scenario domain walls decayed leading to the Universe which we observe today.