28 The field as a region of space with properties

Subject:

Physicists consider the concept of field a difficult concept. When reading textbooks, one gets the impression that it is almost a mysterious entity. The following citations are from different sources:

“The attraction…is independent of the intermediate matter and takes place even in empty space! This endues the space around a magnet with a particular significance; it is called a magnetic field.”

“…magnetic field, region in the neighborhood of a magnet…”, “… there is something rather strange about the space surrounding a charged object…”

“Empty space becomes the carrier of a physical property. Such a space is called a field.“

“field, in physics, region throughout which a force may be exerted;…”

Deficiencies:

A field is a physical system that does not differ fundamentally from other systems, such as an ideal gas, a rigid body or a perfect fluid. Like for other systems, the quantities energy, momentum, angular momentum and entropy have well-defined values. Like other “material” systems, it has a pressure and it may, depending on its state, have a temperature. Like other systems, it consists of elementary portions, in the case of the electromagnetic field the photons.

It is therefore justified to view a field a concrete entity, just as a material system, such as air or water, for example.

In the definitions quoted above the field is termed a “region” or a space”. Pupils and students imagine space as empty. Now they learn that the empty space has properties. There is nothing, but this “nothing” has properties. No wonder, that field is perceived as a difficult concept.

Origin:

For Faraday, the inventor of the field concept, the field concept was simple. It did not make great demands on our capacity for abstraction. For him and his contemporaries space was filled with a medium, the “ether”, about which one had a fairly concrete idea. Fields were no less concrete structures: they were areas of the ether in a particular altered state. A characteristic of this state was that the ether was under mechanical stress.

Maxwell, who further developed Faraday's ideas and gave them a mathematical form, defined the field as follows:

“The Electric Field is the portion of space in the neighbourhood of electrified bodies, considered with reference to electric phenomena.” [1]. Notice that for Maxwell the whole space was filled with ether, thus speaking of the space was the same as speaking of the ether.

From the Michelson-Morley experiment and the theory of special relativity, it followed that the ether did not have the simple mechanical properties, which had initially be expected. Some scientists draw – somewhat hastily– the conclusion that an ether did not exist. And in fact, the term “ether” disappeared from many physics text books (although not from all). Thereby, however, the field concept lost its foundation. Previously the field was a special state of the ether, now it went to be a special state of something that does not exist.

However, the logical failure that had arisen was not perceived. A reason may be that Maxwell himself had defined the field as a region of space. It was not noticed that for Maxwell there was no space without ether.

The period of time in which the field had no conceptual basis should not necessarily have been lasted long. At the beginning of the 20th century, it became more and more clear, particularly through the work of Planck about the heat radiation, that the electromagnetic field is a physical system like other systems. But unfortunately, the field concept in the awkward state in which it had gotten shortly after the publication of the special theory of relativity has survived until today.

Besides this complex historical development of the field concept another fact contributes to the confusion:

The term field is not only used as a name for a physical system but also as a mathematical concept. As such, it describes the distribution of values of a physical quantity in space. Thus one speaks of a temperature, a pressure or a density field. Often, the two meanings of the word are not kept apart. Textbooks sometimes mention an “electric field $\boldsymbol{E}$”. But what is meant by that? The physical system “electric field” or the spatial distribution $\boldsymbol{E}(x, y, z)$ of the physical quantity “field strength”.

Disposal:

When introducing the field concept, orient yourself in how you introduce other, material systems. When introducing the ideal gas, one might begin by saying: “An ideal gas is a substance or a system with the following properties…”. Similarly one could introduce the electric field: “An electric field is a system with the following properties…”

Introducing a field as “a region of space with certain properties” would be like introducing a gas, say air, as “a region of space with certain properties”, which is not incorrect; but nobody would do so, with good cause.

[1] J. C. Maxwell, A treatise on Electricity and Magnetism, Dover Publications, INC., New York, 1954, p.47

Friedrich Herrmann, Karlsruhe Institute of Technology