5 Pure energy

Subject:

In textbooks and scientific reviews one often finds statements that say electromagnetic radiation is pure energy. Here is an example of such a formulation [1]: “When a positron encounters an electron, the two particles annihilate each other and produce pure energy in the form of gamma radiation.” Or another example [2]: “A massive particle and its anti-particle can annihilate to form energy, and such a pair can be created out of energy.” A similar point of view is expressed in the following formulation [3]: “... light can also be described in terms of photons, discretely emitted quanta of energy.”

Deficiencies:

It is obvious that an electromagnetic wave is not pure energy. The electromagnetic field is a physical system, i.e. a thing, for which every standard physical quantity has a certain value, and not only the energy.

So, in general for an electromagnetic field, apart from just the energy, the extensive quantities momentum, angular momentum and entropy also have non-zero values. But intensive quantities also have certain values, just as is the case for other systems. So the electromagnetic field has a pressure at every point. (The pressure depends on the direction and is therefore a tensor.) In certain states, i.e. in those states that are usually called thermal radiation, the field has a certain temperature and a certain chemical potential.

Identifying the radiation with one single quantity is simply not correct. The radiation is a physical system, something that is given to us by nature. Physical quantities on the contrary are products of the human mind. They are tools for the description of systems.

Correspondingly, a photon, the elementary portion of the system “electromagnetic field”, is more than just a quantum of energy. The photon also carries other extensive quantities in addition to energy, such as momentum and angular momentum.

The confusion between the concepts “quantity” and “system” also manifests in a kind of formulation often encountered in which energy and matter are presented as two concepts on an equal footing [4]: “So if galaxies are all moving away from one another […] it seems logical that they were once crowded together in some dense sea of matter and energy.”

Origin:

There are probably two causes for the erroneous identification of the quantity “energy” and the system “electromagnetic field.” Apparently, on the one hand the energy was seen as more than just a variable in a theory, and on the other hand, the field was not taken seriously as a system.

After the introduction of the energy in the middle of the 19th century, its comprehensive significance in science was quickly understood. However, the enthusiasm about the importance of the new quantity led to an overestimation and misinterpretation of it. Energy was conceived, in particular in the circle of the “energeticists”, as a kind of substance. So, one can read in Ostwald‘s 1908 book *The Energy* [5]: “Therefore, the energy is contained in

all real and concrete things as an essential component, which is never absent, and therefore we can say that the energy embodies the actual reality."

On the other hand, the electromagnetic radiation was not accepted as what we today understand by the concept. We now know that it is a system like other system, for instance an ideal gas, or the phonon system of a solid. Like other systems, the electromagnetic field consists of elementary portions. What the hydrogen molecules are to the hydrogen gas and the phonons are to the lattice system of a solid, the photons are to the electromagnetic field.

This misunderstanding of the physical quantity "energy", as well as of the physical system "electromagnetic field", has left its traces. Although we have known better for a long time, we still easily use sentences like those cited at the beginning.

Disposal:

Instead of saying that pure energy is created in a reaction of an electron and a positron, say that a photon results. And instead of saying electromagnetic radiation is pure energy, say that the radiation carries energy, but besides energy it also carries other extensive quantities such as momentum, angular momentum and entropy.

[1] *Scientific American*, December 1993, S. 44

[2] Penrose, R.: *The emperor's new mind*, Oxford University Press, S. 308

[3] *Scientific American*, April 1993, S. 26

[4] *Scientific American*, October 1994 S. 32

[5] Ostwald, W.: *Die Energie*. – Verlag Johann Ambrosius Barth, Leipzig, 1908, S. 5.

Friedrich Herrmann, Karlsruhe Institute of Technology