# 11 Isolated systems

*Subject:*

In order to formulate the conservation of energy or of other physical quantities, we often refer to an isolated system. We imagine a region of space whose boundaries are impermeable for a current of the quantity under consideration. The quotations (1) and (2), which refer to the conservation of energy, are taken from books for the secondary high school and are highlighted in these books.

(1) "In a thermally and mechanically isolated system the total energy is constant."
(2) "In an isolated system the sum of all energies is always constant. The total energy is conserved.

$$E_{\text{total}} = E_1 + E_2 + \ldots + E_n = \sum_{i=1}^{n} E_i = \text{constant}$$

$E_1, E_2, \ldots E_n$ different energy forms"

*Deficiencies:*

The concept of conservation of an extensive or substance-like quantity is not a difficult concept. This has to do with the fact that we can easily represent these quantities pictorially: We imagine them as a kind of fluid or stuff. The conservation of a quantity $X$ can then be stated in the following way: "$X$ cannot be produced and cannot be destroyed."

Here the exact wording doesn‘t matter. Conservation is something that we can easily express with words of the common language.

A consequence of this statement is that the value of $X$ in a region of space can change only if a current of $X$ flows into or out of the region. Mathematically the statement can be expressed in the following way:

$$\frac{dX}{dt} + I_X = 0.$$

Here $dX/dt$ is the rate of change of $X$ in the considered region and $I_X$ is the flow of $X$ through the boundary surface.

A formulation of the principle of energy conservation that refers to an isolated system is a special case of this statement. "The system is isolated" means that there is no flow through the boundary surface. However, the isolation is an unnecessary restriction because the considered quantities are conserved independent of whether the system is closed or not.

To convince myself that the number of my students "is conserved", there is no need to close the door of the classroom. There is no problem if, from time to time, somebody comes in or goes out, as long as I ascertain that the number of students in the classroom increases by one when someone comes in, and decreases by one when someone goes out.

*Origin:*

The fact that we formulate conservation with reference to an isolated system is a leftover of the troublesome development of the concept of energy as a substance-like quantity. Until shortly before the beginning of the 20th century, the localizability of energy was not acknowledged. It was not yet possible to associate a density, a current and a current density with it. In 1887 Max Planck [1] wrote in a historical survey about the energy:

"... according to this definition the amount of the energy is measured only by these external effects, and if one wants to attribute any imaginary material substrate to the energy, then one has to look for it in the environment of the system; only here the energy finds its explanation and therefore also its conceptual existence. As long as one abstracts completely from the external effect of a material system, one cannot speak about its energy, since it then is not defined... On the other hand, we see from the form of the principle as derived formerly that the energy of a system remains constant, if a process carried out with the system does not cause any external effect whatever the internal effects may be. This observation leads us to conceive the energy contained in a system as a quantity existing independently of the external effects." And later: "Meanwhile it is unmistakable... that with this substance-like interpretation of the energy we get not only an increase in the conceptual clearness but also a direct progress in the comprehension... However, as soon as one enters into this question, the uncertainty, which lay before in the concept itself, takes upon the form of a physical problem which in principle can be solved..."

This solution came a few years later by Gustav Mie [2]. He showed that the principle of energy conservation can be formulated locally, namely in the form of a continuity equation. From then on, the strange separation of the system and the effects that can be observed only in the environment was no longer necessary.

Thus, it took about 50 years to prove the substance-like nature of energy. However, the expectation that the quantity had this property was there from the beginning: Ostwald [3] in his 1908 booklet, *The Energy*, praised the work of Robert Mayer with the following words: "For our general investigation the essential result of Mayer's work is the substance-like view of what he calls force, i.e. the energy. For him this was a well-defined entity; the indestructibility and unproducibility are characteristic for its reality."

*Disposal:*

We state the conservation law of the substance-like quantity *X* in the following way: "Energy, momentum, angular momentum, electric charge … cannot be produced and cannot be destroyed."

Just as important are statements about the non-conservation of a substance-like quantity, for example: "Entropy can be produced but cannot be destroyed."

[1] *M. Planck*: Das Prinzip der Erhaltung der Energie. B. G. Teubner, Leipzig, 1908, S. 115.

[2] *G. Mie*: Entwurf einer allgemeinen Theorie der Energieübertragung. Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. CVII. Band, VIII. Heft, 1898, S. 1113.

[3] *W. Ostwald*: Die Energie. Verlag Johann Ambrosius Barth, Leipzig, 1908, S. 59.

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