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RESEARCH ARTICLE

MISUNDERSTANDINGS OF EXTENSIVE QUANTITIES IN PHYSICS TEXTBOOKS

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ABSTRACT

Conservation and non-conservation are two aspects of extensive quantities. Current physics textbooks deal with conservation and non-conservation in some ways that, unfortunately, lead to misunderstandings of extensive quantities. In this paper, we will discuss and explain how this is inappropriate or obsolete and we will make some suggestions for teaching conservation and non-conservation of extensive quantities and finally give a clear and simple formulation for each extensive quantity.

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INTRODUCTION

Physics has been called the science of measurement.[1] Physicists gain information by measuring physical quantities. They use at least two basic physical quantities, an extensive quantity and intensive one, to describe a physical property. For example, in mechanics, they use an extensive quantity, momentum $\boldsymbol{p}$, to measure the amount of motion and an intensive quantity, velocity $\boldsymbol{v}$, to measure the intensity of motion. An extensive quantity represents the integral amount of a property of a body with a finite volume. It is a descriptor of the whole body rather than of some local property. An intensive quantity represents some local property of a physical system and cannot be additive. According to Gibbs's fundamental equation:[2]

$$\mathrm{d}E = \boldsymbol{v}\mathrm{d}\boldsymbol{p} + \varphi \mathrm{d}q + T\mathrm{d}S + \ldots, \quad (1)$$

momentum $\boldsymbol{p}$, electric charge q and entropy S are extensive quantities, and velocity $\boldsymbol{v}$, electrical potential φ and temperature T are intensive quantities. Of course, energy E is also an extensive quantity. Equation (1) also tells us that an intensive quantity determines the magnitude of an energy change related to a change of the corresponding extensive quantity. By measuring physical quantities physicists have found that some extensive quantities like momentum and electric charge are conserved during the processes. They then formulated some physical relationships called conservation laws. However, not all extensive quantities are conserved. For example, entropy is an extensive quantity, but not a conserved one. It is also clear that an intensive quantity cannot be subject to a conservation law.

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Traditional physics textbooks deal with conservation and non-conservation in the following three ways that, unfortunately, lead to misunderstandings of extensive quantities:

1. A conserved quantity, such as energy or electric charge, is often identified with a kind of substance.
2. The non-conservation of physical quantities is never formulated as a physical law.
3. A conservation law is often formulated with reference to an isolated system.

In this note, we will discuss and explain how this is inappropriate or obsolete and make some suggestions for teaching conservation and non-conservation of extensive quantities.

A conserved quantity is not a substance: Physicists try to understand the world primarily through devising general theories that make predictions about wide range of experience, and then checking these predictions against what happens in nature.[3] According to Einstein's epistemology, physical theory is built psychologically upon the experiences of the world of perceptions.[4] Physicists often imagine some conserved extensive quantities as substance-like conceptions to maintain an intuitive understanding of the concepts. For example, they treat electric charge as a substance-like quantity, meaning it can be distributed in and flow through a circuit. Actually, all extensive quantities are substance-like, that is, each has a density and a current density. They can be pictured to be contained in a body, like a gas is contained in a bottle, and to flow from one body to another, like a kind of "stuff".[5] For each extensive quantity X, a relation of the form

$$\mathrm{d}\rho_X/\mathrm{d}t = \nabla \cdot \boldsymbol{j}_X + \sigma_X \quad (2)$$

can be written, where ρ_X, $\boldsymbol{j}_X$ and σ_X are the density, current density and local source density of the quantity X, respectively. The integral form of Equation (2) is

$$dX/dt = I_X + \Sigma_X, \quad (3)$$

where I_X is the current of X and Σ_X is the rate at which the quantity X is created (negative creation is destruction) in a considered region.[6] Thus, physical processes can be simply visualized in terms of the increasing, decreasing, and flowing of these extensive quantities. Pedagogically this picture helps us to get an intuitive feeling for the meaning of the extensive quantities and provides us with an analogous method for the learning of different branches of physics. However, physical quantities are human creations, not discoveries. We can *imagine* an extensive quantity to be a kind of substance, but can never say that it *is* a substance. An extensive quantity is substance-like, but not a substance. According to Aristotle's treatment of categories,.[7] there are four most important categories that should be distinguished in physics teaching, i.e. substance, quality, quantity and relation (or physical law). The world consists of substance that exist in forms of objects and fields. Qualities (or properties, or phenomena) such as motion, heat, etc. are our experiences of the world by observation. Quantities are defined, so they are invented. Physical laws are relations of quantities, so they are discovered by measuring quantities. Observing phenomena, defining and measuring physical quantities to discover physical laws are very important physics practices and the sequence of these practices are just physics learning progressions. So, substance and quantity are two different categories. However, we often find statements in physics textbooks that identify a conserved quantity with a substance. Here are two examples of identifying an energy quantum with a photon. First example[8]:"…, the energy conveyed by an electromagnetic wave is always carried in units whose magnitude is proportional to the frequency of the wave. These units of energy are called *photons* or *quanta*."Second example[9]: "Photons are the energy quanta of which light is composed." Identifying a substance with a single physical quantity is simply incorrect. A photon is a substance, something that is given to us by nature. Energy is a product of the human mind.

An extensive quantity is not necessarily a conserved one: As we have mentioned above, conserved quantities are often mistakenly identified with substances. Historically, this misconception has become a historical burden on physics. Here is an example of this for the development of the concept of amount of heat. We now know that the most fundamental quantities of thermal phenomena are amount of heat and intensity of heat. However, it took an unbelievably long time in the history of physics for these two to be distinguished from each other. For about 150 years (ca. 1600-1750), these two ideas had been confused. Essentially, physicists had been engaged in the measurement of temperature, the intensity of heat. The amount of heat could not be measured. Some thought temperature was a measure of the amount of heat. In 1750 Joseph Black, a Scottish physicist and chemist, interpreted temperature as the intensity of heat, in contrast to the amount of heat. Black distinguished between temperature and quantity of heat.[10] He then introduced the method for measuring the amount of heat. According to equation (1) we can see that Black's concept of quantity of heat coincides perfectly with entropy introduced by R. E. Clausius in 1865. Unfortunately, measurements tell us that entropy is not a conserved quantity: it can be created. In the eighteenth century, conservation principles were very much in the air and a conserved quantity was often mistakenly identified with a substance. As a consequence, the production of the quantity of heat could not be accepted. Many experiments, such as Count Rumford's famous experiment using a boring machine with a blunt tool to raise cold water to the boiling point by means of friction, supported this idea. Thus Black's quantity of heat was considered to be a bad concept, a non-existent substance called caloric. We now might imagine that if entropy were conserved Count Rumford would not have questioned whether Black's quantity of heat is a substance. After conservation of energy was discovered in the 1840s by J. R. Mayer, J. P. Joule and H. Helmholtz, the quantity of heat was replaced by energy because energy is a conserved quantity. Actually Black's quantity of heat was independent of energy. This was clearly proven by Sadi Carnot in 1824. In Carnot's principle[11] he pointed out that the production of work from heat had its cause not in a real consumption of caloric but in a transport of caloric from a hot to a cold body. We can recognize that Carnot's principle is quite correct if we equate quantity of heat (caloric) with entropy and allow it to be created during an irreversible process. It is now clear that the extensive quantity entropy obeys "half a conservation law"— it can be created but not destroyed — and that it is a measure of the amount of heat. It is responsible for making a stone warm, or for melting a piece of ice. It cannot be energy. Energy makes a body more inert, not warmer.[12]If we wish to profit from this idea, we could simplify the teaching of entropy intuitively in ways suggested early by H. L. Callendar,[13] and again by G. Job,[14] G. Falk and Ruppel,[15] F. Herrmann and Schmid,[16] Fuchs,[17] and Burkhardt[18].

A conserved quantity is always conserved: A conservation law is sometimes incorrectly expressed with reference to an isolated system. However, The isolation is an unnecessary restriction because a conserved quantity is always conserved, independent of whether a system is closed or not. There is no problem if a considered conserved quantity flows in or out of the system as long as we ascertain that the quantity in the system increases when it flows in, and decreases when it flows out. We can therefore state the conservation law in a very simple and clear way: "Energy, momentum, or electric charge, can be neither created nor destroyed." In a word, an extensive quantity of a system is not always constant, but it is always conserved according to limited observations.

Summary: An extensive quantity can *be imagined* as a substance, but can not *be considered* as a substance. Conservation and non-conservation are two aspects of extensive quantities. We should formulate both these two aspects clearly and simply for each extensive quantity.

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REFERENCES

1. Francis W. Sears, Mark W. Zemansky and Hugh D. Young, *University Physics*, (Addison-Wesley Publishing Company, 1976), pp. 1.
2. J. W. Gibbs, "On the equilibrium of heterogeneous substances," *Trans. Conn. Acad*. III(1875).
3. Dana Roberts, "Errors, discrepancies, and the nature of physics," *The Phys. Teach*. 21, 155 (Mar. 1983).
4. I. Galili and Y. Lehavi, "The Importance of weightlessness and tides in teaching gravitation," *Am. J. Phys.*, 71, 1127(Nov. 2003).
5. G. Bruno Schmid, "A new approach to traditional physics," *The Phys. Teach*. 24, 349 (Sep. 1986).
6. G. Bruno Schmid, "A up-to-date approach to physics," *Am. J. Phys.*, 52, 794(Sep. 1984).
7. Aristotle, Categories, in *The Basic Works of Aristotle* (Random House, New York, 1941), Chap. 6.
8. Reference 1, pp. 754.
9. A. Einstein and L. Infeld, *The Evolution of Physics*, (Cambridge University Press, 1938), pp. 313.
10. J. Black, *Lectures on the Elements of Chemistry.* J. Robinson ed. Vol. 1., (Longman and Rees, London and William Creech, Edingburgh, 1803).
11. S. Carnot, *Réflexions sur la puissance motrice du feu et sur les machines proper à développer cette puissance*, (Paris, Bachelier, 1824).

12. Hans U. Fuchs, “The continuum physics paradigm in physics instruction III. Using the second law” (Https:// home. zhaw.ch/~fusa/LITEATURE/Literature.htm.).
13. H. L. Callender, “The caloric theory of heat and Carnot’s principle,” *Proc. Phys. Soc*. London 23, 153-189(1911).
14. G. Job, *Neudarstellung der Wärmelehre—Die Entropie als Wärme*, (Akademische Verlagsgesellschaft, Frankfurt am Main, 1972).
15. G. Falk and W. Ruppel, *Energie und Entropie* (Springer-Verlag, New York, 1976), pp. 127-146.
16. G. Falk, F. Herrmann, and G. Bruno Schmid, “Energy forms or energy carriers?”*Am. J. Phys*. 51, 1074(Dec. 1983).
17. Hans U. Fuchs, “Entropy in the teaching of introductory thermodynamics,” *Am. J. Phys*. 55, 215(Mar. 1987).
18. H. Burkhardt, “System physics: A uniform approach to the branches of classical physics,” *Am. J. Phys*. 55, 344(Apr. 1987).

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