Thermodynamics on the first day of teaching What is Thermodynamics?

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Abstract

There is an analysis of the different textbook definitions of thermodynamics. The common points and main differences are analyzed in the context of the beginning of an introductory course. There is also a discussion about the criteria used to define Thermodynamics in a way that will be helpful in its teaching.

Keywords: Thermodynamics, Physics Education, Didactics of Physics.

Resumen

Se presenta una discusión sobre las diferentes definiciones de la Termodinámica que pueden encontrarse en los libros de texto. Los puntos en común así como las principales diferencias se analizan en el contexto de su presentación en el inicio de un curso introductorio. De igual forma se discuten los criterios utilizados para presentar una adecuada definición de la Termodinámica que sea de utilidad en el desarrollo de su enseñanza.

Palabras clave: Termodinámica, Educación en Física, Didáctica de la Física.

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I. INTRODUCTION

Teaching Thermodynamics is not an easy task. Although some magnitudes like energy, heat, work and temperature seem to be intuitive and closely related to everyday life, it is not easy to define them in an ordered logical arrangement devoid of ambiguities. On the other hand, other basic concepts like entropy are very abstract and difficult to relate to common observation. This situation means that misunderstandings and different criteria could appear more frequently than is desirable. A lot of papers can be found in the literature about this topic [1, 2, 3].

The first problem arises at the very beginning of the Thermodynamics course, when one tries to explain to the students what Thermodynamics is.

When looking for a definition in the textbooks, one can find almost as many definitions as authors, which is a clear indication of the difficulty of clearly stating the boundaries and the scope of Thermodynamics. Moreover, in most of the definitions, there are references to particular variables or magnitudes like temperature, energy, or heat which are only properly defined in the scope of Thermodynamics itself.

The adopted definition at the beginning is relevant because it focusses the objectives and the ideas to be developed in the course. It is the moment to clarify the starting point and the objectives to be reached.

The aim of this paper is to discuss how to define Thermodynamics at the beginning of an introductory course in such a way that it will be helpful in the further development of the course. This is done by comparing different topic definitions, trying to find their common points, and highlighting those which should be included in its definition.

II. DEFINITIONS

There are plenty of different common textbook definitions of Thermodynamics:

M. W. Zemansky and R. H. Dittman [4] in their *Heat and Thermodynamics*: "Thermodynamics is the branch of natural science that deals with the macroscopic properties or characteristics of nature and always include the macroscopic coordinate of temperature for every system".

A. B. Pippard [5] in his *The Elements of Classical Thermodynamics*: "The science of Thermodynamics may be said to be concerned with the understanding and interpretation of the properties of matter in so far as they are affected by changes of temperature".

H. B. Callen [6] in his *Thermodynamics and an introduction to Thermostatistics*: "Thermodynamics is the study of the restrictions of the possible properties of the matter that follow from the symmetry properties of the fundamental laws of physics".

C. B. Finn [7] in his *Thermal Physics*: "Thermodynamics concerns with relationships between the large scale bulk properties of a system which are

measurable, such as volume, temperature, pressure, elastic moduli and specific heat, which are often called macroscopic properties"

G. Carrington [8] in his *Basic Thermodynamics*: "Thermodynamics deals with the bulk properties of matter and the process by which these properties are changed".

P. A. Rock [9] in his *Chemical Thermodynamics*: "Thermodynamics is the science of the utilization and conversion of energy".

P. Atkins [10] refers to it in his *The Laws of Thermodynamics* as "… this boundlessly important and fascinating aspect of nature" and states in his *Equilibrium Thermodynamics* [11] that "Thermodynamics describes and correlates the directly observable properties of substances".

J. Aguilar Peris [12] in his widely used book in Spanish speaking countries, *Curso de Termodinámica*, proposes that it is "The analysis of macroscopic physical phenomena related with heat and temperature".

E. Fermi [13] in his classic book *Thermodynamics* does not defines it explicitly but he focuses the discussion from the very beginning on the state of a system and its transformations, stating that systems are macroscopic and so are the variables describing their states.

H. C. Van Ness [14] in his *Understanding Thermodynamics* says that "Thermodynamics is the study of energy and its transformations".

M. Bayling [15] in his *A Survey of Thermodynamics* describes it as "The science of heat" and Y. A. Cengel and M. A. Boles, [16] in his *Thermodynamics* uses the term "The science of energy".

This search could go on forever because there are lots of textbooks on Thermodynamics, but the results are similar. We simply compare those definitions with the one from the Oxford Dictionary [17]: "The branch of physical science that deals with the relations between heat and other forms of energy (such as mechanical, electrical, or chemical energy), and, by extension, of the relationships between all forms of energy".

II. ANALYSIS

The concepts used in the definitions can be classified into different levels. In the first level, there are definitions asserting that Thermodynamics is a part of Science as it is:

- The branch of Natural Science [4].
- The branch of Physical Science [17].

While others do not include it in a more general group and they simply define it as:

- The science of [15, 16, 9].
- The analysis of [12].
- The study of [6].

The last three can be considered as synonyms and as regards the first two, Natural Science includes Biology which is not included in the Physical Sciences. As its field of application includes chemical reactions, biological systems, and many of the engineering systems, it can be seen that Thermodynamics is part of these sciences although as its methods and definitions are developed in the scope of Physics it can also be seen as a division of Physics which is applied in the scope of the remaining sciences.

Regarding the object of study we can find that Thermodynamics studies the:

- Macroscopic properties of nature [4].
- Macroscopic physical phenomena [12].
- Bulk properties of matter [8].
- Large scale bulk properties of a system [7].
- Directly observable properties of substances [11].
- Properties of matter [5].
- Restrictions of the possible properties of matter [6]

The first five items emphasize the macroscopic properties of nature and all of them have the same sense. The last one focusses attention not only on the analysis of the properties of matter, but also on the explanation of why some values of those properties, although expected, are not produced.

Regarding the matter in question we can find different assertions related with Thermodynamics:

- The macroscopic coordinate of temperature for every system is always included [4].
- Properties of matter in so far as they are affected by changes of temperature [5].
- Physical phenomena related with heat and temperature [12].
- Science of heat [15].
- Relations between heat and other forms of energy [17].
- The science of energy [16].
- The utilization and conversion of energy [9].
- The study of energy and its transformations [14].
- The large scale bulk properties of a system which are measurable, such as volume, temperature, pressure, elastic moduli and specific heat, which are often called macroscopic properties [7].
- Properties of matter and the process by which these properties are changed [8].
- Properties of the matter that follow from the symmetry properties of the fundamental laws of physics [6].

The first nine include the study of phenomena also related with temperature, heat or energy. However, although all of these magnitudes are clearly within the scope of Thermodynamics, none on its own is enough to cover a general description of it.

The tenth one is more general and focusses the attention on both its states (properties of matter) and on its transformations (process). The last one goes a step further and focusses the attention on the symmetry properties of the fundamental laws of physics.

III. DISCUSSION

A definition can include what something does or how something works (function), or how something is organized

or put together (structure), as well as how something is compared to other members of its class by illustrating the differences (analysis). On the other hand, a good definition must use previously defined terms, must help to classify and quantify the object of definition (definiendum), and must be devoid of counterexamples. A common way is to divide a definition in two parts: the genus, which is the category or class from which the definiendum is a part of, and the differentia which is the characteristic or group of characteristics that set it apart from other members of the genus. It is useful to describe the origin of the word, the use or purpose, and the characteristics that make it different from other concepts that might be confused with it.

Listed below are items that, although some of them are shared with other subjects, they correspond with scope or methods of Thermodynamics:

- The study of the properties of nature.
- The description of those properties by directly or indirectly measurable parameters.
- The use of simplified models from which the set of relevant aspects of the system can be extracted.
- The finding of relationships between parameters, and therefore the ability to make predictions on unknown parameters or behaviors.
- The study of macroscopic systems.
- The use of macroscopic variables.
- The analysis of both particular states and the transformations or processes between these states.
- The above transformations can take place spontaneously as well as by means of mechanical or other (thermal) interactions.
- Some change in the internal state of the system is expected to have happened.
- Its methodology is based on a reduced set of postulates (laws), which allow the introduction of several characteristic variables or magnitudes (temperature, energy, heat, entropy).
- The above variables are subjected to conservation laws (energy) or extremum principles (entropy) that characterize the allowed transformations and the final states of evolution of the analyzed systems.

When reporting that Thermodynamics is the science of, or a branch of science, the first four items are implicitly assumed, and the other items can be included in the analysis of the macroscopic properties and internal transformations of nature.

The development of Thermodynamics is focused on the description of the equilibrium states. In order to do this, three new variables, temperature, energy and entropy are included. Several others appear as a combination of the above three with the work coordinates and conjugate variables of the system. These new variables are key to a particular set of transformations, of which heat transfer, heat transformation in work, and spontaneous evolution are particular cases.

The fact that there is a definite direction in the transformations produced (heat goes from hot to cold bodies) is a primal fact of spontaneous evolution, and entropy is a tool to explain the extent to which those transformations are produced. So, in short, the analysis of the states of a system, and the description of spontaneous (or driven) transformations, and the extent to which those transformations are produced are the backbone of this scientific subject.

So according the above discussion the following definition of Thermodynamics is suggested here for the first day of teaching:

> *Thermodynamics, [from the greek "thermos" (warm) and "dynamis" (power)] is the science that deals with the description of the internal transformations of macroscopic systems and their interactions with the surroundings.*

But if we were to use a shorter definition we would be inclined to propose:

> *Thermodynamics is the science of the macroscopic description of the internal transformations of nature.*

Or even shorter:

> *Thermodynamics is the science of transformations of nature.*

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