Symmetry in thermodynamics: the adiabatic concept

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Abstract. Symmetries regarding system-surroundings interchange are used to overcome persistent misunderstandings in thermodynamics, namely to redefine the concept of adiabatic process. Additionally, we emphasize the use of symmetry as a powerful tool to clarify concepts and definitions, which is relevant from a didactical and pedagogical perspective.

1 Introduction

Thermodynamics is a very formative area of physics for students (and for teachers) because their subtleties are a constant challenge to the critical and scientific spirit.

Although some subtle concepts are addressed in a didactical and pedagogical perspective, resorting to the development of teaching strategies that go through models, analogies, metaphors, intuition, among others, it is my conviction that most of the conceptual difficulties in thermodynamics are better dealt with in scientific-mathematical strand, using universal concepts which, given their mathematical nature, are unassailable.

One of those concepts is that of symmetry, which is a powerful tool to clarify concepts and definitions and we use it here to show how the adiabatic concept can be tuned to be consistent with heat definition and with the type of boundary in the problem under analysis [1]. The adiabatic concept is very relevant in thermodynamics as it appears, for instance, in Caratheodory's statement of the second law [2] as well as it is studied in its practical aspects.

2 Thermodynamic process as an interaction

A thermodynamic process is an interaction between two entities: the system and its surroundings. The physics of the interaction does not depend on which is the system or surroundings, so that fundamental laws and quantities should be invariant under a system-surroundings interchange, i.e. they should be *process-invariant*. Process-invariants are very important because they express properties of a process that are independent of what is labelled as system or surroundings [1]. However, some concepts break the symmetry between the system and surroundings, and it is vital to understand that such concepts depend on the choice of the system (and hence of surroundings). Among these, the most paradigmatic are the concepts of heat and work, which remain challenging concepts because they are usually regarded (though *wrongly*) as invariants under system-surroundings interchange. Heat δQ and work δW are defined through surroundings variables only as [1]

$$\delta Q = -T_{\mathrm{e}} \mathrm{d} S_{\mathrm{e}}, \tag{1}$$

$$\delta W = P_{\mathrm{e}} \mathrm{d} V_{\mathrm{e}}, \tag{2}$$

where T, S, P and V are, respectively, temperature, entropy, pressure and volume, the subscript "e" (for external) indicating surroundings variables. Because of definitions (1) and (2), the entropy generation – *which is a process-invariant* – always occurs within the system [1, 3], a feature not usually addressed in the literature.

3 Adiabatic process: only calorimetric heat matters

Even though *heat*, which is given by (1), is not a process-invariant, it must have a component whose value is a process-invariant, this component being due to a difference between system and surroundings temperatures (that is why we call it *calorimetric heat* δQ_C) and which only exists if the wall separating the system from surroundings is *diathermic*, i.e. *non-adiabatic*. Since the nature of the wall is a process-invariant and the definition of adiabatic process should reflect the wall properties, *adiabatic process* should be defined as one for which $\delta Q_C = 0$ and *not* one for which $\delta Q = 0$. Similarly, an *adiabatic wall* should be defined as one that inhibits δQ_C and *not* one that inhibits δQ. The other heat component is denoted by δQ_D and discussed in detail in [1].

Figure 1 illustrates the symmetry breaks in a thermodynamic process due to the choice of the system and to the concepts of heat and work. Process-invariant quantities are also emphasized: wall nature, value of calorimetric heat, entropy generation and dissipative work [1].

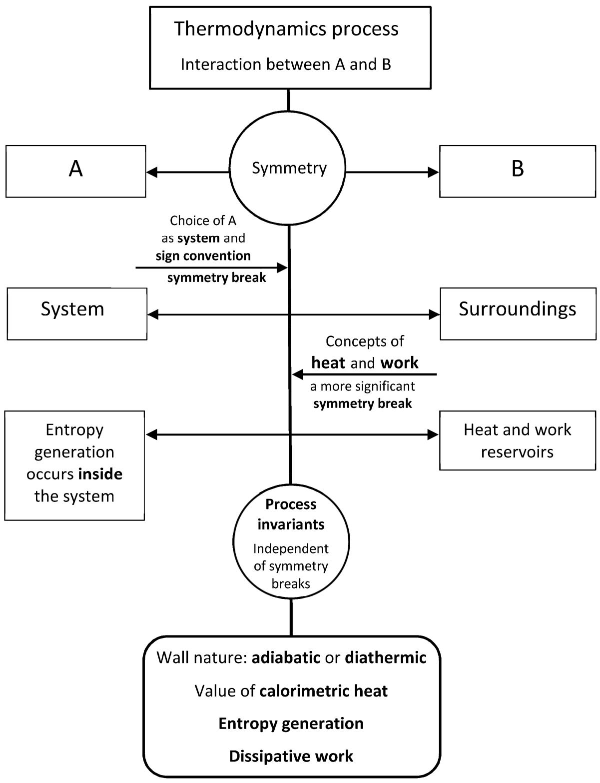

Fig. 1 Thermodynamic process regarded, initially, as a symmetric interaction. The choice of system and the concepts of heat and work break the symmetry, however some relevant quantities remain process-invariant.

4 Conclusion

In this work the symmetry is used to show that the concept of adiabatic process, as it is presented in the literature, should be reformulated. Other concepts and definitions must also be clarified using considerations of symmetry, as discussed in [1].

References

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