6 The equivalence of heat and work

Subject:

Heat is disordered energy according to some [1], the kinetic energy of the unordered molecular movement according to others [2]. To still others it is the kinetic and potential energy of the thermal molecular motion [3], the energy which can be added to an object by thermal contact [4], a short name for the expression $U - W$ [5], the bound energy TS [6], the integral $\int TdS$ [7], or a questionable and superfluous concept [8]. What is it really?

Deficiencies:

Clausius himself used two heat measures: the heat H contained in an object, which he imagined as kinetic energy of the molecules, and the "supplied heat" Q, where $Q = H$ is only valid in exceptional cases. Under the above cited examples we easily recognize the descendants of these two parents. The diversity of opinions is an expression of the unpleasant circumstance that no energetic quantity exists that simultaneously represents all the desirable aspects of the concept of heat. As with a too-short blanket, one is obliged to do without one or the other property. Depending on what one chooses to stress, the compromise will be different. From the fact that in spite of this ambiguity the mathematical treatment gives the same results, one can conclude that the equivalence postulated by Clausius is meaningless for thermodynamic calculations. Then what is it good for?

Origin:

The question is as old as physics. The answer given by R. Clausius around 1850 in his first law, in which he postulated the equivalence of heat and work, is essentially still considered valid today, but it is obviously ambiguous.

Disposal:

If we do without this postulate, we win a new freedom. We do not need it in order to formulate the conservation of energy. We also don't need it to define what heat is. It is easy to give an operational ("fundamental") definition of the heat concept. Such a procedure is usually used in physics only for the definition of some basic quantities, such as length, time and mass. One specifies the unit and how to determine equality to the unit and multiples of it. However, one can employ this procedure, which makes a correspondence between a given concept and a physical quantity, in many other cases, for instance for the definition of energy, momentum, angular momentum, charge, amount of material, entropy, and for the metrization for concepts like the amount of heat, amount of data, disorder or randomness. The most surprising result from proceeding in this way is that a concept of an amount of heat that is unbiased by scientific interpretation does not result in an energetic quantity, but in Clausius's entropy S [9]. This effortless access to the most important thermodynamic quantity (apart from the temperature) permits a far-reaching house-cleaning of thermodynamics. Concepts such as enthalpy, free energy, energy degradation, process quantity and state function can be disposed of at the same time. The fact that a small error can have such far-reaching consequences, not in the scientific calculus but in its semantics, should warn theoreticians, whose attention is focused mainly on the consistency of the calculations, and alarm educationists, who have to deal with the consequences.

[1] F.J. Dyson:“What is heat?” Scientific American 1954, 191 (No. 3), S. 58 - 63.

[2] R.W. Pohl: “Mechanik, Akustik, Wärmelehre”; Springer: Berlin 1962, S. 248.

[3] C. Gerthsen, O.H. Kneser, H. Vogel: “Physik”; Springer: Berlin 1986, S. 193 - 197.

[4] C. Kittel: “Physik der Wärme”; Wiley & Sons: Frankfurt 1973, S. 133.

[5] M. Born: Physikal. Zeitschr. 1921, 22, S. 218 - 286.

[6] H.H. Steinour: “Heat and Entropy”; J. Chem. Educ. 1948, 25, S. 15 - 20.

[7] G. Falk, W. Ruppel: “Energie und Entropie”; Springer: Berlin 1976, S. 92.

[8] G.M. Barrow: “Thermodynamics…”; J. Chem. Educ. 1988, 65, S. 122 - 125.

[9] The following assumptions together with the choice of a heat unit are sufficient for its unambiguous metrization:

1) each object contains heat, whose amount cannot decrease, if it is thermally insulated.

2) objects of the same kind and in the same state contain equal amounts of heat.

3) the heat content of a composed object is equal to the sum of the heat contents of its parts.

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