Historical burdens on physics

30 Measuring entropy

Subject:
Often entropy is introduced in such way that the impression results that values can be obtained only through complicated mathematical calculations.

Deficiencies:
Entropy and temperature are the most important quantities of thermodynamics. Entropy is the energy-conjugated extensive quantity of the intensive quantity temperature. Between entropy and temperature there is the same relationship as between electric charge and electric potential, or between momentum and velocity. Thus it is reasonable to expect that in the teaching of thermodynamics entropy and entropy currents should play an important role, just as electric charge and electric currents in electricity or momentum and force (= momentum current) in mechanics. The usual introduction of entropy does not cope with this expectation.

When mentioned for the first time, it is usually stressed that entropy is a state function [1]. But why is it claimed that it is a function? In the first place entropy is a physical quantity or in mathematical terms, a variable. It is a function only if its dependence on other physical quantities is given. And depending on which other quantities we choose, this function is different.

And why is it stressed that entropy is a state function or variable? Almost all physical quantities are state variables. This fact, however, is so evident that it is not considered to be worth mentioning. Only because the traditional introduction of entropy does not allow for an intuitive idea of the quantity, one clings to this property, although it is not at all distinctive.

The most important deficiency when introducing entropy is that no measuring procedure is presented. The complicated introduction makes us believe that a measurement is difficult, if not impossible.

 Actually, entropy is one of those quantities that are the easiest to measure. Entropy values can be determined with good precision with only the aid of kitchen equipment.

Origin:
See [2]

Disposal:
Of course, we do not want to dispose entropy and its measurement, but the prejudice that entropy is hard to measure.

How can entropy be measured? Let us first define the task more exactly: Determine the entropy difference of 5 liters of water at 60 °C and at 20 °C.

We begin with the water at 20 °C and heat it with an immersion heater until its temperature is 60 °C. When doing so we stir the water and measure the temperature as a function of time. The energy flow or power $P$ from the heater into the water is known.
From \( dE = TdS \) follows

\[
dS = \frac{dE}{T} = \frac{Pdt}{T} .
\]

We thus get the value of a small increase of the entropy \( dS \) as the quotient of the delivered energy \( dE = Pdt \) and the absolute temperature \( T \). Since the temperature changes as we are heating, we have to integrate or to sum from \( T_1 \) to \( T_2 \) in order to get the total entropy:

\[
\Delta S = P \int_{T_1}^{T_2} \frac{dt}{T} = P \sum \frac{\Delta t_i}{T_i} .
\]

As long as the temperature changes are not too great compared to the average absolute temperature \( \bar{T} \) we get approximately

\[
\Delta S \approx \frac{P \Delta t}{\bar{T}} ,
\]

or in words: The increase of the entropy is equal to the power of the immersion heater multiplied by the heating time and divided by the absolute temperature.


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