Workshop on Second Law of Thermodynamics
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STUDENT VIEWS ON LEARNING THERMODYNAMICS

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At a workshop dealing with the second principle of Thermodynamics where the exchange of information between industry and university is emphasized, the issue of "Teaching and Learning" cannot be omitted. This is particularly clear if we accept the idea that even the most prominent men in the field of Thermodynamics took over a state of knowledge from their predecessors developed it, and passed on their new ideas to their successors. From this viewpoint every scientist is a link in a long chain of scientific conversation which has lasted up to the present day and which will hopefully stretch into the distant future.

This continuity can, however, only be achieved if every year we manage to inspire enough students and communicate that fascination with Thermodynamics which every disciple of our art must at some time experience. It is clear to see in this respect that the universities play a decisive role. Without a new generation of highly qualified scientists we would come in only a short time to a scientific - and only a little later to a technical - standstill. The discussion of "Trends in Teaching" is a legitimate task for this workshop.

It must be mentioned that opinions expressed in this Panel Discussion are essentialy personal, as indeed are the views I am about to express. I believe that we share the understanding that it is only through considering a variety of viewpoints that we can find a successful way forward. We have no love of standardized teaching methods or even worse, following a single required text-book as national or international standard. We don't hesitate to accept competing schools of thought: to the contrary we believe that such competition encourages progress. Uniformity easily leads to hiatus.

Let's now talk about Thermodynamics, using our same image that even the greatest discoveries were only part of a scientific dialogue which exists over generations and through which scientific progress occurs. Looked at in this way it is hard to define the exact point in time when a discovery takes place. Although we will continue to associate the discovery of the f irst principle with Robert Julius Mayer and James Prescott Joule, and of the second principle with Sadi Carnot and Rudolf Clausius, that doesn't necessarily mean that we underestimate their predecessors in these discoveriessuch asChristian Wolff or Count Rumford, nor their successors who completed and consolidated the theories and who established the axiomatic system.

Our students often say:
Thermodynamics can't be learned in one go!

What they probably want to express with this is a certain discomfort that at first they need to redefine more accurately familiar terms such as heat, work and temperature, before taking in new concepts such as enthalpy, entropy and thermodynamic potential, without, at this point in time, being able to understand the reason for this process of learning. Nor can they yet recognise the universal validity of concepts. These conceptual difficulties, which to a certain extent are also to be found in other sciences, can be partially but not totally ameliorated during teaching by frequent references to everyday experiences.

However, difficulties remain and reflect the necessity to divide tuition into two parts. Thermodynamics can indeed not be learned in one go!

Our students often also say:
One can't understand Thermodynamics, only get accustomed to it.

This remark reflects the desire for proofs of the axioms of Thermodynamics, i.e. the principles. To this we can only answer, that such proofs do not exist.

The issue of how the validity of the principles can be established is an old and familiar problem for the theory of cognition. One way to test their validity migh appear to be by deduction- that is the logical reduction from the general to the specific statement. However, this approach cannot succeed since nobody is in the position to check all the possible consequences of a general statement: there would always remain the possibility that one deduction might not correspond with reality and so invalidate the system of axioms.

In order to resolve this dilemma, the Austrian philosopher Sir Karl Popper proposed that the principles of a scientific system must remain refutable by deduction. "An empirical scientific system must remain open to practical experience". According to Popper, therefore, it is the issue of refutability - rather than simply refutation - which is decisive.

Looked at in this way our laws of nature - which are also the axioms of thermodynamics - take on a new appearence. They are empirical statements since they derive from actual experience. They are also empirical since they are not "metaphysical". They can, however, never be proved in the sense that their validity cannot finally be established. The place of this proof is taken by the process of contant refutability: the principles must therefore constantly prove themselves.

This requirement for constant refutability is very appropriate to the character of Thermodynamics. The priciples can be given in their shortest formulation as a negative viz. :

the first principle: there is no perpetuum mobile,

the second principle: there is no perpetuum mobile of the second kind.

If we want to prove the non-existence of something we can only say: "Up until now we have not been able to find this", but we must leave the possibility open that one day it will be found. Non-existence is thereby not proved but remains constantly refutable.

In practice there are subtler ways to refute the axioms. It is possible to test experimentally mathematical formulations which are derived from the principles and which are quantifiable. In this group, amongst many others, may be counted the Clausius-Clapeyron equation, the electromotive power of galvanic cells and the constants of chemical equilibria. Since all previous efforts to refute the principles have failed we consider the principles to be a reliable basis of our knowledge. Coming back to our students, we must accept that for beginners it is hard to grasp this logical structure of Thermodynamics. This is particulary true since the degree to which the principles of Thermodynamics influence our daily life as well as many areas of applied sciences causes our students to perceive them as "long-proven" laws of nature. The students must simply "get accustomed" to the fact that the principles are empirical and by their very nature cannot be proved; and that they are only a reliable basis for our understanding and use so long as it has not been possible to refuse them but that such a possibility remains open. This concept is far removed from the "naive" approach of the students.

The strictly axiomatic structure of Thermodynamics allows its essential contents to be summarized in a few statements. These are the fundamental equations, also called canonic equations. The expression "canonic" derives (originally) from ecclesiastical law; it means for us the combination of wide validity with a particularly simple structure. Since all further properties can be derived from these equations, the associated quantities are termed thermodynamic potentials.

The most important consequences of the existence of these potentials is thermodynamic consistency. This means that all properties which can be derived from an equation of state (which is written as a thermodynamic potential) are interconnected according to the principles of Thermodynamics. In order to set up such an equation of state experimental data are required: for the equation of state of steam for example, more than 12 000 individual values are used.

In order to test the reliabilty of such an equation, comparisons must be made with alternative experimental values which contain higher derivatives of the potantials. Amongst these are heat capacity, velocity of sound or Joule - Thomson coefficient. If the outcome of such a test is satisfactory it is possible to determine all further properties by calculation - that is without further experiments. In this sense thermodynamic consistency brings important economic benefits since otherwise the number of individual measurements required would exceed financial and personal resources.

So our students have a right idea about how thermodynamics can be learned. In a first course they should learn the general fundamentals and the most important applications such as the principles, the equation of state and the cycles. Only in a later course can we impart a real understanding of the logical structure of Thermodynamics by including concepts as thermodynamic potential and thermodynamic consistency.

We can only hope that each year we succeed in educating enough able thermodynamicists on whom we can depend both to ensure that scientific research progresses and to explore new possibilities in the wide fields of technical and industrial application.