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Reply to the DPG report about the Karlsruhe Physics Course

Translation by F. Herrmann

Overview

The response consists of three parts. Literature is listed in the first part, which is related to the issues addressed in the DPG report. It only shortly explains, to which details the individual publications relate. This literature refutes the objections that are brought forward in the DPG report.

The second part comment the allegations in detail.

The third part [not translated] is an essay by Georg Job from the Institute of Physical Chemistry of the University of Hamburg. Job was the most important source of ideas for the thermodynamics and chemistry sections of the KPK, namely the chapters 10 to 14 and 24 to 26 of the lower secondary course and the whole volume 2 of the upper secondary course.

Literature on which KPK is based

Mechanics with momentum currents

The equivalence of force and momentum flow was first demonstrated by Max Planck:

M. Plack: Physikalische Zeitschrift, 9. Jahrgang, Nr. 23 (1908), p. 828

Excerpt: “As the constancy of energy entails the concept of an energy flow, the constancy of the quantity of motion necessarily entails the concept of the flow of the quantity of motion, or for short the ’momentum flow’ ”

Thereafter the concept momentum flow or momentum flux is found in the physical literature, but it appears to be a concept at an advanced level.

Weyl, H.: Die Naturwissenschaften 12, III (1924)

Landau, L. D., Lifshitz, E. M.: Theory of Elasticity, Chapter 1, Section 2, Pergamon press, Oxford (1959)

Landau, L. D., Lifshitz, E. M.: The Classical Theory of Fields, Chapter 4, S. 91, Pergamon press, Oxford (1962)

Falk, G.: Physik – Zahl und Realität, Birkhäuser Verlag Basel, 1990, S. 70.

Fuchs, H.: The Dynamics of Heat, 2nd edition, Springer, New York, 2010, S. 75.

Its potential for the teaching of beginners was seen in the 1970s by ourselves and independently by diSessa.

Herrmann, F.: Mechanik – Abriss einer Neudarstellung, Konzepte eines zeitgemäßen Physikunterrichts, Heft 3, Hermann Schroedel Verlag, Hannover (1979), S. 80-87.

DiSessa, A.: Momentum flow as an alternative perspective in elementary mechanics, Am. J. Phys., Volume **48** 365-369 (1980)

The usefulness of the concept at an intermediate level was studied in our group. Several publications resulted from this work:

Herrmann, F., Schmid, Gary B.: Statics in the momentum current picture, Am. J. Phys. **52**, 146 (1984)

Herrmann, F., Schmid, Gary B.: Momentum flow in the electromagnetic field, Am. J. Phys. **53**, 415 (1985)

Herrmann, F., Schmid, Gary B.: Analogy between mechanics and electricity, Eur. J. Phys. **6**, 16-21 (1985)

Heiduck, G., Herrmann, F., Schmid, Gary B.: Momentum flow in the gravitational field, Eur. J. Phys. **8**, 41-43 (1987)

Grabois, M., Herrmann, F.: Momentum flow diagrams for just-rigid static structures, Eur. J. Phys. **21**, 591-601 (2000)

The entropy as heat

Since the beginning of the 20th century it has been repeatedly pointed out in the scientific literature that the properties of the physical quantity entropy coincide to a large extent with those of the heat concept of our everyday life. Moreover, entropy coincides in several respects with the heat concept of physics between 1780 and 1850 (which was a state variable).

Callendar, H. L.: The caloric theory of heat and Carnot's principle, Proc. Phys. Soc. London **23**, p. 153 (1911)

Excerpt: „Finally, in 1865, when its importance was more fully recognised, Clausius (Pogg. Ann. 125, p. 390) gave it the name of 'entropy', and defined it as the integral of *dQ/T.* Such a definition appeals to the mathematician only. In justice to Carnot, it should be called caloric, and defined directly by his equation $W = AQ\,(T - T_0)$, which any schoolboy could understand. Even the mathematician would gain by thinking of caloric as a fluid, like electricity, capable of being generated by friction or other irreversible processes. Conduction of caloric is closely associated with the electrons, and the science of heat would gain, like the science of electricity, by attaching a more material conception to the true measure of a quantity of heat, as distinguished from a quantity of thermal energy."

Job, G.: Neudarstellung der Wärmelehre– Die Entropie als Wärme, Akademische Verlagsgesellschaft Frankfurt (1972)

Hund, *F*.: Geschichte der physikalischen Begriffe (Teil2) B·I·-Hochschultaschenbücher Bd. 544, Bibliogr. Institut Mannheim (1978)

Excerpt p.105: "Historically the concept *Q* which came into being in order to explain the calorimetric experiments of the 18. century and proved its worth for the description of heat conduction in the 19th century was set at the beginning of the science of heat, and was related to *S* much later. Thus the irreversible processes were the starting point. Today one could also (as it is done by G. Job) put the concept *S* at the beginning of the teaching of heat phenomena which would be introduced by means of the reversible Carnot process and one would call this concept heat. One would get an understanding of the calorimeter and heat conduction by means of the energy conservation law. By using the energy conservation law one would get an idea of the concept entropy ("heat") supply $\Delta_z S$ as well as entropy ("heat") production $\Delta_p S$ and also of the concept of thermal energy supply ΔQ and specific thermal energies c_p and c_v."

Falk, G.: Entropy, a resurrection of caloric – a look at the history of thermodynamics, Eur. J. Phys. **6**, 108-115 (1985)

Excerpt: "The entropy introduced by Clausius was, contrary to general belief, not a new physical quantity but the reconstruction of the 'quantity of heat' conceived about one hundred years earlier by the Scottish chemist Black. The same quantity was also used under the name 'calorique' by Carnot in his work which laid the foundations of thermodynamics. That entropy and Black's 'quantity of heat' are only two names for the same physical quantity is not only of historical interest but is of significance to the teaching of thermodynamics as well. It asserts that entropy can be visualized as a kind of substance which obeys 'half a conservation theorem': it can be created but not destroyed."

Job, G., Rüffler, R.: Physikalische Chemie - Eine Einführung nach neuem Konzept mit zahlreichen Experimenten, Vieweg+Teubner Verlag, 2010.

Excert p. 45: “Entropy *S* and temperature *T* are central concepts of the science of heat. Whereas temperature is familiar to everybody, entropy is known to be particularly difficult, a sort of “black sheep” among the physicochemical concepts. In former times school books did not treat it at all, introductory physics books only mention it, and even experts try to avoid it.

But why does one evite entropy? Actually it is a simple concept: rather exactly what in everyday life we understand by heat! It is, roughly speaking, the stuff, that has to accumulate in the stockpot in order to heat the meal, it is what the coffee loses when the cup gets cold, it is what is produced in the electric hotplate, in the microwave oven or in the oil stove or what is conveyed with hot water, spread by means of the radiators and held together by insulating walls in the apartment and woolen clothes in the body. Unfortunately, in science the name “heat” had been assigned to another quantity and thus *S* had been deprived of its natural interpretation. As a consequence, entropy is now introduced in an abstract manner, i.e. indirectly by integration over the ratio of energy and temperature, and it thus became conceptually difficult to handle.”

Fuchs, H.: The Dynamics of Heat, Springer New York 2010

Excerpt p. 116: „The quantity I have been calling *heat* in the interpretations of thermal processes was called caloric by Sadi Carnot and his contemporaries. This easily visualized and intuitively understood quantity best fits what after 1850 was called *entropy* in physics, chemistry, and engineering. Therefore, the concept of entropy which, in standard presentations of thermodynamics is considered to be formal, derived, and non-intuitive, has simple and intuitive roots. It is analogous to volume and to charge in fluids and electricity, respectively.“

Magnetic charge and magnetic monopoles

The quantity which is called magnetic charge in the KPK, is called in the literature mostly magnetic pole strength; sometimes it is called magnetic charge, and Maxwell calls it amount of magnetism.

Maxwell, J. C.: A treatise on Electricity and Magnetism, Volume 2, 1873

Excerpt, S. 7: „377. The quantity of magnetism at one pole of a magnet is always equal and opposite to that at the other, or more generally thus: *In every Magnet the total quantity of Magnetism* (reckoned algebraically) *is zero.*

Sommerfeld, A.: Elektrodynamik, Akademische Verlagsgesellschaft Leipzig 1964

Excerpt, p. 39: "We now come back to (9) and write the divergence of the vectors on the left and the right hand side. Then we get the Poisson equation for magnetostatics, namely

$\Delta\psi = -\rho_m$."

Excerpt p. 78: "We come back to the bar magnet and to the definition of the pole strength *P*. From our point of view it is given as an extensive quantity by:

$P = \oint H_n \, d\sigma$,

[…]. This definition of *P* corresponds to the definition (7.2) of the magnetic space density $\rho_m = \text{div } H$ and tells us that *P* is equal to the sum of all the magnetic quantities $\rho_m \, d\tau$ in the corresponding half of the bar." [Translation F. H.]

Macke, W.: Elektromagnetische Felder, Akademische Verlagsgesellschaft Leipzig, 1960

Excerpt p. 78: "All conclusions and solutions of the electrostatic theory (1) can be transferred directly to magnetostatics (2). However, all magnetic charge densities are caused by dipoles. Correspondingly (224.7) describes

$$\rho_m(\vec{r}) = -\sum_i \vec{m}_i \frac{\partial}{\partial \vec{r}} \delta(\vec{r} - \vec{r}_i) \qquad \vec{m} = q_m \vec{a}$$

the magnetic pole density of magnetic dipoles m_i, which are located at $\vec{r}_i$". [Translation F. H.]

Jackson, J. D.: Classical Electrodynamics, 2nd edition, John Wiley & Sons New York, 1975

Excerpt p. 193: „Then with (5.93) it becomes a magnetostatic Poisson equation,

$\nabla^2 \phi_M = -4\pi\rho_M$

with the effective charge density,

$\rho_M = -\nabla \cdot M$ " [M is the magnetization]

Remarks concerning the various allegations

By “the author” we mean the author or the authors of the DPG report. Citations from the report are indented.

Mechanics with momentum currents

Page 2 and page 3

> If a force or a momentum current respectively accelerate the wagon to the same extent, both quantities should be equal in amount and direction. Whereas this is true for the amount, there can be a difference as far as the direction is concerned, as will be shown in the following.
>
> …
>
> In Fig. 2a a truck is pulling a trailer towards the right (this situation is comparable with that of Fig. 1). The KPK momentum current points toward the left, whereas the force points to the right hand side. In the next figure 2b the truck and the trailer are rotated by 180°: According to KPK the direction of the KPK momentum flow does not change when going from Fig. 2a to Fig. 2b. On the contrary, the force has followed the rotation of the truck by 180°: In both cases, Fig. 2a and fig. 2b, the force points towards the tractor truck. This is reasonable, since it is the cause of the acceleration of the trailer.

The cause of the problems of the author is that he confounds the flow direction with the direction of the **current strength vector**.

In physics one understands by the flow direction of a scalar quantity the direction of the **current density vector**.

If the flowing quantity itself is a vector quantity, and thus also the current strength, then the current density is a second rank tensor. In our case this tensor is called the stress tensor. One can consider the three components of the momentum and the momentum current strength separately and treat them like 3 scalar quantities (at the condition that the coordinate system is not rotated anymore). Now to each of the momentum components corresponds a current density vector, and thus a flow direction. The components of these three vectors are the three lines of the stress tensor (written as a matrix of its cartesian components).

Obviously, the direction of the momentum flow vector must be distinguished from the direction of the current strength (= force) vector. It seems to me that the author has identified these directions.

In the corresponding section of the KPK, vectors are not yet available. They have not yet been introduced. Thus one operates only with momentum of one single direction. There is not yet a current strength vector arrow, since there is only one component of the current strength. There is, however, already the direction of the current density vector.

Later, in chapter 6, section 6.2 under the title “The direction of flow and the direction of that which flows” KPK discusses this problem. There the following recommendation is formulated:

“Don’t mistake the direction of the path with the direction of the momentum being transported.”

An additional difficulty arises, when for instance two students cannot agree upon the directions or their coordinate systems. Then, they will give different answers to the question of what is the direction of the KPK momentum current. Both answers can be correct simultaneously! In view of such problems one begins to ask, if the direction of the KPK momentum current corresponds to an objective reality or if it is only an arbitrary definition. These considerations will be continued in the next section.

This is a problem indeed. But such “arbitrary” definition are very frequent in physics. Before giving the value of any physical quantity we have to choose a zero point or the reference frame. A car moves in the direction East with a velocity of 40 km/h. Is this velocity positive or negative? That depends on how we orient the axis of velocities. But we could also indicate the velocity of the same car with respect to any other reference body, the sun for instance. This is a problem which the student must learn to handle anyway. Every physics course has to get along with it. This kind of problem arises as soon as we begin to treat a phenomenon mathematically.

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Since no movement of the system can be perceived, a bright student should ask how we can prove that something is really flowing through the spring. A somewhat more difficult question might be: Why in a obviously symmetric system one direction is distinguished? And if the teacher pretends that this is the case, how can he prove it? […]

Is there a measuring instrument for the KPK momentum current that is comparable to an ammeter? Such a device is not described in the school book.

It is described in the KPK, on page 36:
– extended spring: momentum flow in one direction,
– shortened spring: momentum flow in the other direction.

Purchasable spring scales however cannot react on pressure.

By the way: We have constructed a spring scale, that can change polarity. As the direction of the deviation of the pointer of an ammeter changes when the current is inverted, our momentum current meter also marks values of opposite sign when its terminals are exchanged. Attention: Exchange the terminals does not mean to invert the whole meter (this would not change anything with an ammeter either), but the inner and outer terminals must be interchanged. The inner terminal ti the central rod of the device, the outer is the external cylinder.

Thus the spring scale must be compared with an incandescent lamp and not with an ammeter.

The insensitivity against the direction of the current of the incandescent lamp is due to the equation $P = U \cdot I$, in which both factors change their signs upon a change of the direction of the current. No such argument holds in the case of the spring scale. Thus, the spring corresponds indeed to the ammeter.

Thus, the direction of the KPK momentum current can be arbitrarily changed, independently from what goes on with the system by only choosing a new coordinate system. From this we conclude: The direction of the KPK momentum current is not a property of the system.

The fact that the sign and the amount of a quantity changes upon a change of the reference system does not mean that the corresponding quantity does not describe a property of the system.

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In nature there is not such a current. Therefore, there is no room for the KPK momentum current in the structure of physics and certainly no in the teaching of physics.

If there is a momentum current in physics or not, can be seen if the concept is intorduced in the text books, and it is.

Entropy and heat in thermodynamics

Page 6

Also regarding the concepts heat and energy the students have a certain pre-understanding. This is certainly not true for the entropy.

We do not think so. The students have a good pre-understanding of the entropy, see the literature indicated above, for instance Callendar: „In justice to Carnot, it should be called caloric, and defined directly by his equation $W = AQ\,(T - T_0)$, which any schoolboy could understand.“

It is well-known that entropy is one of the most difficult physical quantities.

This is a wide-spread opinion. However, the opposite opinion is also wide-spread. (See our literature).

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But this is not a reason for identifying entropy with heat, even not with a “colloquial heat”. Both have different measuring units, and this is only one of the reasons why they cannot be identical. Heat is measured in Joule, entropy in Joule/Kelvin.

It is not true that KPK identifies entropy with heat or any other energetic quantity.

Moreover, the logic of the sentence is not really correct. One cannot say that heat in the colloquial sense is measured in Joule.

What we do is commonly accepted in physics: We try to generate in pictorial idea of a physical quantity by showing that it measures something that we know from our everyday life.

Here examples of how the concept force is introduced in two well-known university text books:

“In the same way as the concepts length and time, also the concept force has a direct intuitive meaning, which does not require any other explanation. A force is exerted by our muscles, it is perceived as a muscle perception by whom exerts the force.”

“We believe that with our muscular feeling we have a direct, at least qualitative idea of the concept of force.”

This correspondence between the quantity force and the feeling of our muscles is certainly not unambiguous.

The arguments of the KPK are based almost exclusively on the equation $\Delta S = \Delta Q/T$, which defines in the limited case of a reversible heat supply or removal ΔQ at a temperature T the change of the entropy ΔS.

The equation does not exist in KPK. It might be that the authors do not distinguish between

$\Delta S = \Delta Q/T$

and

$P = T \cdot I_S$

(P = power, I_S = entropy current).

> It [the KPK] applies the equation also on irreversible processes, although in this case $\Delta S \geqslant \Delta Q/T$.

KPK does not apply it.

> In this way it hinders the access to irreversible processes which are tremendously important for an understanding of our world.

Irreversible processes are one of the central subjects or the KPK thermodynamics. They are treated extensively already in the lower secondary school beginning in the 5. lesson of the thermodynamics chapter.

> There are important processes in which the above-mentioned formula cannot be applied, because entropy changes without a supply of heat.

We do not apply this formula. We discuss at length how entropy can change without the supply of heat, see the volume for the lower secondary school sections 10.5 and 11.3, and the volume for the upper secondary school sections 1.5, 1.11, 2.7 and 7.4.

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> … so that after the temperature equalization there is more entropy in the system than at the beginning.
>
> This is not a small effect that can be ignored, but this entropy increase is the essence of this experiment! It is the real driving cause for this process: The entropy increase determines that the heat transfer occurs from the hotter to the colder container, but never in the reverse direction. This crucial aspect is simply concealed by the KPK.

I agree with the technical content of the authors remarks. However, the question is how to carry the ideas into the class room. The KPK treats the role of the entropy production for the process of heat conduction an page 133. One should not reproach to the KPK that a given subject is not treated at a certain page of the course. Moreover, in the majority of school books this subject is not treated at all.

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> Here KPK stumbles over its own definition, namely that the entropy can only be made to increase by supplying heat and thereby increasing the temperature.

KPK does not say that. It would indeed be nonsensical. KPK says something else: Entropy increases either by an entropy supply or by entropy production. In the present case there is entropy production, and this is clearly said.

Here KPK points to a previous observation, where the temperature decreases when the gas expands. It is an adiabatic expansion whereby mechanical work is done. The KPK insists correctly, that in such a process the entropy remains constant, but it uses it (for us not understandable) to explain the expansion into the vacuum, where there is an increase of the entropy, as KPK finally also states!

Independently from that, one sees immediately, that the temperature of a gas does not change, because in an expansion into the vacuum no work is done on the external system.

The procedure that is employed by the KPK is common practice in thermodynamics. In order to understand how a given quantity behaves when the system gets from state A to state B, one choses another path than that taken actually by the system. In this way it can become easier to make the balance of some quantities. In the KPK the transition from the state with a small volume to that with the greater volume is done via another path than a free expansion: First an isentropic expansion. Thereby temperature decreases. To get into the actual final state B, entropy must be supplied from outside. By this procedure it is easier to understand that the entropy of B is indeed greater than that of A. And at the same time one learns: At constant temperature a gas contains more entropy the greater its volume is. If the author wants to put this result at the beginning then this is his decision about the teaching methodology, against which we do not object. But we have chosen another way. Regarding our procedure, see also *Falk-Ruppel*, p. 248-249.

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KPK does not mention this physical fact, but gives in table 1.3 (page 14) the values of the entropy conductivity of substances by simply dividing the heat conductivity by an arbitrarily chosen average temperature.

No, there is no division by an arbitrarily chosen average temperature. If one is really interested in precise values, one should divide the energetic heat conductivity at a given temperature by exactly this temperature. Both, the heat conductivity and the entropy conductivity depend on temperature.

It identifies two different physical quantities and thereby makes an elementary mistake. The fundamentally incorrect identification of heat and entropy that is made at the beginning immediately causes contradictions.

Once more: We do not identify two different quantities, we do not identify entropy and the heat of physics.

Magnetic charges

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> This is not a singular case, but as we have said previously, the search for magnetic monopoles has been unsuccessful. Until now there is no experimental justification for magnetic charges.

The author does not distinguish between the physical system “magnetically charged particle” and the physical quantity “magnetic charge”. There are no bodies or particles that carry a net magnetic charge. But in order to express this fact, we need the physical quantity magnetic charge. It cannot be my task to defend this quantity, since it exists in the literature, see above. Its name is *quantity of magnetism*, *pole strength* or *magnetic charge*. Those who want to insist that this charge is due to the magnetic polarization call it *magnetic polarization charge* or *bounded charge.* I once more want to cite Maxwell, since he is expressing it particularly clearly: “The quantity of magnetism at one pole of a magnet is always equal and opposite to that at the other, or more generally thus: *In every Magnet the total quantity of Magnetism* (reckoned algebraically) *is zero.”*

> For a student this might sound convincing. But then he will ask, how these charges can be spatially separated, so that one can speak of real charges and not only of the properties of a bar magnet.

This is an unusual requirement for a physical quantity. What is meant by *real* charges? Why should the magnetic charge not be necessary to describe a magnet? Electric charge also describes the properties of something, of electron for instance.

> “The question is not, if magnetic charges exist or not, the question is if its introduction is advantageous.” [Citation from the teachers guide]. Now this is an argument, which completely discredits the proceeding of the KPK in the eyes of serious scientists.

Regarding the question of why physical quantities are introduced, I would like to cite some authors whose arguments have more weight than my own opinion:

1. From a dialogue between Einstein and Heisenberg, retold by Heisenberg in *Der Teil und das Ganze, Piper & Co Verlag München 1969 S. 91-92* [translation F. H.]:

Einstein: But you do not seriously believe that a physical theory can adopt only observable quantities.

Heisenberg: I believed that precisely you used this idea as the basis of your theory of relativity? You had insisted, that one cannot speak of an absolute time since this absolute time cannot be observed. Only the indications of clocks, in a moving or resting reference frame, are relevant for the determination of the time.

Einstein: Maybe that I used this kind of philosophy, but nevertheless it is nonsense. I can say it more prudently: it may be heuristically valuable, to remember what is really observed. But from a principal point of view it is completely incorrect to found a theory only on observable quantities.…

2. *Einstein, A.:* Foundations of the theory of relativity, Akademie Verlag Berlin, 1970, p. 6 [translation F. H.]:

“Therefore, according to my conviction it is one of the most ruinous feats of the philosophers that they have transferred certain conceptual foundations of the natural sciences from the realm of the empirical and practicable, which is accessible to logical control into the unassailable height of the aprioristic realm. Although it is certain that concepts cannot be logically deduced from experience (or otherwise), but are in a certain sense free creations of the human spirit, they neither are independent of the kind of experience, as for instance the garments of the shape of the human body.”

3. *Falk, G., Ruppel, W.:* Mechanik, Relativität, Gravitation, Springer-Verlag Berlin 1973, p. 2 [translation F. H.]:

“Finally it would be an error to suppose that the objectivity of physics is due to the fact that its concepts do not depend on human fantasy or on humans in any other way. Actually physical quantities are inventions of the human spirit, which serve make the confusing variety of the phenomena around us manageable by means of simple rules. ”

Aether/Vacuum

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> In fact one can consider the vacuum of the quantum field theory a modern successor of the aether. However, a decisive difference to the classical aether is, that the vacuum of the quantum field theory is lorentz-invariant, satisfies the theory of relativity and thus does not characterize a particular reference frame.”

From these remarks I cannot deduce, that it should be inappropriate to consider the vacuum of the QED the carrier of electromagnetic fields.