

On a Report by the German Physical Society Concerning the Karlsruhe Physics Course

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This text may be cited using the urn:
<http://nbn-resolving.de/urn:nbn:de:bvb:355-epub-300353>

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1 Background and Intention of the Present Text

1.1 Summary

The Report on the Karlsruhe Physics Course (KPC) commissioned by the German Physical Society (DPG) mentions several points the referees consider to be conceptual and technical deficiencies. Our arguments will deal with this criticism and relate it to established physics textbooks and to the original texts where the KPC has been published. First, however, we will take a professional look at the deficits the DPG Report claims to have found. We will then ask if the conclusions drawn from them have any real basis. We have come to the conclusion *that the referees' arguments are largely unsubstantiated or have been based upon statements that are not contained in the KPC text.*

In brief, within a fixed coordinate system the momentum current vector within the KPC is identical to the force; the KPC relates the qualitative term 'heat' to the scientific term 'entropy', rather than identifying the scientific terms 'heat' and 'entropy'; and the magnetic charges in the KPC are the sources of the magnetic field \vec{H} , rather than of the magnetic field \vec{B} —a notion well established in the magnetism community.

It is our goal to move the discourse about the KPC to a professional level. Since the report commissioned by the DPG is in German and refers to German KPC-textbooks, many citations given in this text refer to these textbooks as well. However, English Versions of the KPC and the teacher's manual can be found in the web.¹

1.2 Basic Considerations Concerning the Karlsruhe Physics Course

The KPC-approach was successfully documented in an extensive series of refereed publications (Herrmann & Schmid, 1984, Herrmann & Schmid, 1985b, Falk, 1985, Herrmann & Schmid, 1985a, Heiduck, Herrmann & Schmid, 1987,

¹http://www.physikdidaktik.uni-karlsruhe.de/publication/pub_fremdsprachen/englisch.html (6th June 2014)

Herrmann, 2000, Grabois & Herrmann, 2000). Nearly simultaneously, and independent of the first publication of Prof. Herrmann in 1978 (in German), a similar concept was developed at MIT by diSessa (1980). In addition, within the *Introductory University Physics Project* (Di Stefano, 1996; Coleman, Holcomb & Rigden, 1998) the idea to base physics upon conservation laws, rather than Newton's equations was put forward (Moore, 2003).

The KPC uses the observation that the relation between currents, current densities and surfaces through which currents flow, is always the same for the extensive quantities charge, energy, entropy, amount of substance, momentum and angular momentum. This approach challenges the imagination because an image of what is flowing can be gained by using everyday notions only in the case of amount of substance—in all other cases we need abstract quantities for which appropriate mental images must first be constructed in the classroom.

It is justified to ask why a teacher would want to choose a concept based upon the flow of abstract physical quantities. The answer can be given in at least two ways—empirically or pragmatically. To answer the question empirically means to investigate the KPC's adequacy *in the field*, i.e., in schools. Empirical investigations of the effectiveness of didactic approaches (of the KPC as well as of many other approaches) have been conducted and published both nationally and internationally. There are many reasons why—as a consequence of these investigations—one particular concept might not take precedence so that teachers, curriculum developers and researchers in didactics would all decide for it. One of these reasons is that the expectations we have for the results of education are subject to constant social change. This means that teaching must always be in flux as well and in the best case, can make use of continuing developments. The co-existence of many different didactic approaches can be understood as an engine for such continued developments. We will return to this in Section 7

A pragmatic answer to the question of why one should choose this concept would be the following: The concepts of charge, energy, entropy, amount of substance, momentum and angular momentum permeate all of physics. To describe a multitude of various phenomena they must be understood as abstract quantities. It can be considered an essential task of physics teaching—whether in schools or at universities—to create a certain familiarity with these quantities. An advantage of the KPC is that it combines the abstract nature of physical quantities with a powerfully suggestive metaphor—the metaphor of flow. This flow is familiar in the case of amount of substance (water, for example).

The developers of the KPC see an advantage of the metaphor of a flow because a common perspective arises for different disciplines of physics, disciplines, what were originally considered to be different. This perspective allows interconnections and structural commonalities of different phenomena.

The ultimate importance of this argument for the KPC can again be discussed either empirically (see above) or *normatively*. The normative answer would be one that ascertains whether or not such a unified approach should be seen as a gain for basic science education or if we should forgo this in favor of other aspects. One should be aware that this is a question concerning theory of education and not physics.

2 Momentum Currents in Mechanics

The conceptual motivation of the KPC makes use of the fact that, despite their undoubted historical successes, Newton's laws contradict the status of modern physics in at least three ways:

1. They contain action-at-a-distance in which the motion of a body can be transferred to other bodies at any distance by instantaneous changes to the forces. This contradicts Einstein's finding that the effects of a force are conveyed at finite speed and cannot exceed the speed of light.
2. Newton's First Law requires concepts of (contrary to the theory of relativity) Newton's absolute space and absolute time. Without the absolute space and time the ›linear-uniform motion‹ cannot be explained.
3. The laws fail to describe ›point masses‹ (or particles) when their relative distances are of the order of the de Broglie wavelength.

It is a great handicap to understanding modern physics when a system of laws is used as the basis of a physics course that has been considered outdated for the last 100 years, because it suggests a world-view that is unfounded in important respects. The commercial GPS system provides everybody with an experimental falsification of Newton's laws. The GPS system would not work if it did not take into account the general relativistic corrections to Newton's gravitation theory in its algorithms. Until now, each generation of school and university students has had the problem of needing to replace the view of the classical physics they learned in the first years by more modern concepts that contradict what before were considered to be irrevocable laws. Building a mathematics course, for example, upon foundations that have long been considered untenable would be unthinkable.

The developers of the KPC made it their goal to ease this problem by introducing an alternative representation of mechanics and electrodynamics, based upon another basic principle that is still valid today. This basic principle is the conservation of momentum with its corresponding continuity equation. The question of whether or not this approach is better or worse for students or pupils than the traditional one, should be kept separate from that of its conceptual correctness.

The KPC interprets Newton's laws to be expressions of momentum conservation in static force fields where force takes the role of a momentum flux or momentum current. The terms force and momentum current are synonymous. Use of the term *current* illustrates that a conserved quantity can only be altered by inward or outward flows and cannot be changed by production or destruction. Newton's 2nd Law, or rather the continuity equation for momentum currents, determines the algebraic sign for the force or momentum current vector relative to the time derivative of the momentum. Of course, the force vector's sign (or the momentum current vector's sign) depends upon the chosen coordinate system.

In contrast to other flowing quantities such as electric charge, energy, or amount of substance, a vectorial nature of momentum leads to an additional mathematical complication that *must be avoided in elementary courses in schools*. Since each of the three momentum components obeys its own conservation law, the momentum current density \mathbf{G} that along with the oriented surface \vec{A} determines the momentum current

$$\vec{F} = \mathbf{G} \cdot \vec{A} \quad (1)$$

is not a vector, but a second order tensor—namely the (negative) stress tensor known from elasticity theory, electrodynamics, or hydrodynamics.² Its elements determine the mechanical state of stress of an elastic medium. These complications are avoided in the examples considered by the DPG report.

2.1 Rotational Transformations

In a single-dimensional case, the mechanical stress is described by a simple scalar which can be either positive (compressive stress) or negative (tensile stress) and retains its sign when the coordinate system is inverted or rotated by 180°. The alleged inconsistencies described in the DPG report emerge because the direction of the force vector, or rather, the momentum current vector, is mistakenly not distinguished from the direction of flow of the x -component of momentum. The dashed lines with arrows in Fig. 2 of the DPG report *do not* represent the vector of the momentum current (which is identical to the force vector drawn there as well) but the current density vector for positive x -momentum. Correspondingly, the word ›momentum‹ is written next to the vectors (to indicate the direction of flow of positive x -momentum) rather than ›momentum current‹. In the original caption in the KPC, the sentence ›...both times, x -momentum flows in the negative x -direction‹ expresses this clearly. The referees also added a Fig.2c where the KPC statement holds as well, because by rotating, the x -axis as well as the direction of flow are reversed. The referees correctly write:

»The comparison of Figures 2a and 2c clearly illustrates that

²This sign reflects the different sign conventions in continuum mechanics and Newtonian mechanics.

the position of the KPC-momentum-current is closely related to the orientation of the coordinate system.«

This is logical because rotating a coordinate system causes positive x -momentum to become negative x -momentum. If the sign of flowing charge is reversed in an electrical circuit, the orientation of the electric current density vectors will change correspondingly.

2.2 Measurability of the Direction of the Momentum Current

The DPG report correctly states that the principle *actio = reactio* makes it impossible to say whether positive momentum flows to the left or negative momentum flows to the right. It is correct that the state of mechanical stress of an elastic medium does not give preference to a particular direction of flow. Exactly the same problem appears in electricity. An ammeter cannot decide whether positive charge flows to the left or negative charge flows to the right because the Lorentz force used to measure this as well as the electric potential drop will be the same in both cases. The direction of flow used in a technical setting is determined by the arbitrary convention that tells us the flowing charge is positive. In the subject of electricity, we do not conclude from this arbitrariness that electric current has no »objective reality« and that it has »no place« in physics as stated by the DPG referees. The method used by the KPC for determining the direction of a current of momentum is completely analogous to the standardized method used to determine the technical direction of a current.

The conclusions of the DPG report (p. 6) stating that »The question asked at the beginning of whether the KPC statements about direction of momentum currents can be checked experimentally, must be negated. For this reason, the direction of momentum current introduced by KPC is considered an arbitrary convention having no objective reality: This current does not exist in nature. Therefore, KPC's momentum current has no place in physics and certainly not in physics education« simply ignores the fact that momentum current is identical to force. The KPC can avoid such misunderstandings by making it even clearer in the text that the concepts of force and momentum current are synonymous.

The referees concluded from the mirror symmetry in their Fig. 3a, that the orientation of the closed momentum current flowing in this static setup cannot be determined experimentally and therefore cannot exist. This is, of course, incorrect because according to Eq. 1, the value of the momentum current is determined by the product of the momentum current density \mathbf{G} (which in a single spatial dimension is a scalar) and a surface oriented either clockwise or counter-clockwise. The arbitrariness of the orientation of this surface vector corresponds to the principle *actio = reactio* making the KPC (or

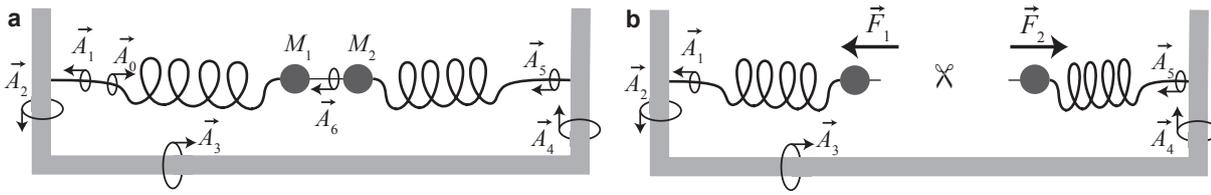


Figure 1: **a** Illustration of a closed momentum current circuit, analogous to Fig. 3 of the DPG report. The spring constant, the length L of the of the springs in the relaxed state and the masses, are the same, so that the arrangement is perfectly symmetrical. The oriented surfaces \vec{A}_1 to \vec{A}_6 indicate the path of the closed momentum current circuit. There is tensile stress in the springs and in the horizontal part of the frame, the stress is compressive. Conservation of momentum is expressed by the fact that the integration of the stress tensor yields the same value for the x -momentum current F_x (having the same sign!) for every one of these surfaces. Shearing stress appears along the surfaces \vec{A}_2 and \vec{A}_4 through the vertical parts of the frame and the direction of the flowing momentum is perpendicular to the direction of the current; this is described by the off-diagonal elements of the stress tensor. The momentum current flowing through surface \vec{A}_1 indicates the force by which the left end of the spring is pulled to the left ($F_{1x} < 0$). If the orientation of the surface is reversed as it is for surface \vec{A}_0 , we obtain the equal and opposite force according to the actio = reactio principle by which the spring pulls the frame to the right ($F_{0x} > 0$).

b If the connection between the two spheres with masses M_1 and M_2 is cut the circuit will be interrupted and the masses will initially be accelerated outward. Whereas the sphere on the left emits positive momentum (\vec{F}_1), the sphere on the right absorbs positive momentum (\vec{F}_2). According to the sign convention of the KPC, this flows from the left via the springs and frame to the right-hand sphere. If the lengths of the springs go below their rest lengths L , the signs of all the local stresses as well as the directions of momentum currents will reverse. The spheres slow down and the well-known harmonic oscillation centered on the equilibrium positions will be established. In the initial state of **b**, the forces acting upon the spheres (i.e., the momentum currents) are at a maximum but the speeds are equal to zero, exactly as in the statistic (!) arrangement in **a**. For this reason, a *constant non-zero momentum current must flow* in **a** whose sign is determined by the orientation of the surfaces. If the opposite sign convention of that of the KPC is used, and all the surfaces are reoriented, the direction of flow if momentum will change and after interrupting the connection, negative momentum will initially flow from the sphere on the right to the sphere on the left. Physically, this is the same process!

another) sign convention necessary. A non-zero *momentum current density* is compatible with the symmetry of the arrangement because \mathbf{G} is *not a vector* but a scalar, or rather, a second order tensor in two or three dimensions. Therefore, the closed momentum currents described by the KPC can be uniquely determined by the value of the momentum current density \mathbf{G} (the mechanical stress) and the oriented surface \vec{A} . This is illustrated in the figure 1 in this text which represents a symmetrical situation analogous to that in the DPG report in both static and dynamic situations.

The referees also criticize that the label ›positive momentum‹ is dependent upon a reference system while the sign of a charge is absolute, meaning it is determined independently of the chosen coordinate system. This difference, though, is inherent to the quantities charge and momentum and not specific to the KPC. It must appear in all representations of physics. The fact that the values of certain physical quantities depend upon a reference system is not unique: Relativity theory doesn't say that such quantities have no objective reality.

According to relativity theory, the fundamental equations of physics should be formulated in such a way that they are invariant under transformation of the reference system. In order for this to be the case, the quantities in an equation must transform in a manner that leaves the equation unchanged when the coordinate system is changed. This criterion is satisfied by both the momentum current vector (force) and the momentum current density tensor (negative stress tensor).

The momentum current used in the KPC is nothing else than a consistently used elementary form of the well-known physical concept of the stress tensor.³ It must perfectly have a place in physics as is illustrated by the fact that the distinguished textbook Landau and Lifschitz (1991, pp. 14) devotes an entire section to it under the title ›Momentum current‹.

³See Kattmann, Duit, Gropengießer and Komorek (1997), for remarks about how to create elementary representations.

⁴http://www.dpg-physik.de/veroeffentlichung/stellungnahmen_gutachter/kpc-ergaenzung.pdf

2.3 The Technical Addendum to the Report: On the Question of Open and Closed Integration Surfaces

The same referees wrote *Additional Remarks Concerning the DPG Review of the Karlsruhe Physics Course*⁴, dated the 9th of April 2013. In the summary (p. 3), they state: »*The KPC actually abandons Newton's axioms and goes over to continuum mechanics. This obscures the fact that continuum mechanics is fundamentally based upon Newton's three axioms.*« Although this statement is correct, for its part it obscures the fact that the continuum mechanics derived in this way, is only a limiting case of a more general general-relativistic continuum mechanics where Newton's laws are no longer valid. This is why momentum conservation should be considered more fundamental than Newton's laws, because the latter are simply incompatible with modern physics. The question to be answered is whether or not the KPC allows the contents and basic relations of school physics to be reproduced without undue effort. This is the case because the contents are the same, only their interpretation is sometimes different.

The authors continue: »*A correct momentum current is formed by integration over closed surfaces*« [emphasis in the original]. *Instead, the KPC integrates over arbitrary, and especially open, surfaces. Therefore, the KPC does not generally satisfy conservation of momentum, but, especially in static situations, introduces fake momentum currents where no static momentum flows.*« It should be noted that the referees give no reason why integration over an open surface should not be allowed. Contrary to this statement, in the case of flow phenomena, integrating over open surfaces is the norm. In the case of water flowing through a pipe or electric charge flowing through a wire, it is obviously sufficient to integrate over the pipe or wire cross section to find the (strength of a) current. If only closed surfaces were allowed, only currents equal to zero would be found for closed circuits. It is impossible to infer the vanishing of a local current density from the vanishing of a global current. This is impossible because (non-zero) currents to different parts of a closed surface may add up to zero. This is the case in the upper part of Fig. 2 of the Addendum to the Report.

Obvious examples of this fact are closed electric circuits and the ring currents in oceans. A ring current can be set in motion by induction in a closed electrical conductor. Its existence cannot be experimentally demonstrated by the build-up of charge but by the magnetic field produced by the current. Analogously, the momentum current in a medium expresses itself by the deformation of that medium. Exactly like the momentum current density, the magnitude of the deformation (strain) is a local quantity and is independent of whether the momentum current circuit is open or closed. This is illustrated in Fig. 1a and b of our response. It is irrelevant to a state of stress of the springs whether or not it is static (closed momentum current circuit in Fig. 1a) or changes dynamically (open current circuit in Fig. 1b).

The referees' reasoning boils down to denying the existence of ocean currents by arguing that they could only be proven if the sea level somewhere were to significantly change.

The referees have expended much energy upon the example of hydrostatic pressure so we will now use this to once again explain the argument of the KPC: Consider a vertical pipe filled with water in a homogenous gravitational field. The lower end of the pipe is sealed with a valve. Following the prescription of the referees, we integrate the stress tensor of the water over the (closed) water surface and find (using the KPC rule) that a positive net current of z-momentum flows into the water because the pressure at the lower end of the column of water is higher than at the upper end. Integrating over the cylindrical mantle makes no contribution. Then why isn't the water set in upward motion? Because an equal but opposite net current of z-momentum flows out via the gravitational field (which has its own stress tensor that describes the transfer of momentum through the gravitational field) so that the total momentum current transferred relative to the water vanishes. When the valve is opened, and effects of friction are ignored, the pressure difference and the positive contribution to the momentum current both disappear. The water column then begins moving downward. Is this description really more complicated than the traditional one?

In closing, we wish to respond to the referees' comment that by eliminating Newton's first Law, the concept of inertial system is also eliminated. As [Falk and Ruppel \(1975, §30\)](#) describe in detail, inertial systems can be defined by simply applying the balance of momentum of an N -body system: An inertial system is present when the bodies in it only exchange momentum with each other and the momentum of the center of mass in the N -body system is constant. If the latter is not satisfied, the N -body system must exchange momentum with another system. [Falk and Ruppel \(1975\)](#) call this other system the inertial field. According to the principle of equivalence of general relativity, this is identical to the gravitational field because it is impossible to decide whether the N -body system is accelerated by a gravitational field or if the reference system used is being accelerated and is therefore not an inertial system. The referees have used an invalid objection again.

3 Entropy and Heat in Thermodynamics

For the last 150 years, introductions to thermodynamics have suffered from conceptual difficulties having to do with the multitude of changes to the meaning of the word »heat«. These difficulties are demonstrated by the fact that the subject of »experimental thermodynamics« is unpopular even among students at university level. The usual definition for »heat« used by physicists today is »*heat is a form of energy.*« Unfortunately, this definition actually says nothing at all because

energy is by no means specific to thermodynamics. It is found everywhere in physics. If we wish to introduce the energy form ›heat‹ as opposed to other forms of energy not only qualitatively (›heat is random motion‹) but by measurable quantities, we will have to use entropy. New university level textbooks (Kittel & Krömer, 2001, Schroeder, 2000, Stierstadt, 2010) acknowledge this by introducing entropy from the start by its relation to statistical physics. To date, this is not done in schools because the basic concepts have not been made available in current didactics. As so often, the concept of entropy introduced phenomenologically.

Right from the beginning, the KPC structures thermodynamics in a way that conforms with this specialized branch of science by using conjugated pairs of extensive and intensive quantities instead of using the energy forms heat and work as inexact differentials. To do so, the KPC relates entropy to the everyday perception of heat without describing entropy as a new type of substance (just as it would not describe energy, electric charge, or momentum as a substance). Heat has no unit in everyday life (not even the Joule), because we do not measure there. It has been sufficiently documented how the everyday concept of heat interferes with temperature (compare, for example, Duit, 1986, Kesidou & Duit, 1993). Introducing the physical concept of ›heat‹ in school can be considered a standard problem as long as it is made clear in class what is meant by it scientifically and what is not. The assigned meanings in this case are assertions and do not necessarily result from scientific considerations because everyday terms are not scientific terms. To relate the every-day term ›heat‹ to the technical term heat by introducing the technical term heat as a transfer form of energy is not the only possibility. We can just as well point out the closeness of the every-day term ›heat‹ with the technical term entropy. In both cases, students will have to reinterpret their every-day concept if they want to argue scientifically.

The authors of the KPC promote their assertion stating that the physical quantity entropy is very similar to the pre-scientific everyday idea of ›heat‹. This allows an intuitive understanding of a difficult quantity independent of the statistical interpretation of entropy but compatible with it. The relation between entropy and thermal energy transfer is only developed later on (a discussion of the relation between chronology of introduction and conceptual hierarchy can be found in Section 7). This is analogous to electricity where initially, electric charge is introduced, then electric current and next electric conductivity. The fact that energy is always transferred along with charge is discussed only later.

If one decides to introduce entropy, and not energy as the typical quantity for thermal phenomena, a unit is needed. In the KPC, the unit Carnot (Ct) is introduced for this. As soon as the relation to energy has been established, the units of entropy and energy can be related to each other: $Ct = J/K$

The referees claim that in the KPC, the entropy and the scientific term heat have been made synonymous. This statement is nowhere to be found in the KPC textbook. Instead, entropy is introduced as a basic quantity for describing thermal phenomena. It also states that it has a lot of similarity to what is called ›heat‹ in everyday life. The statement about this in the KPC is correct, without a doubt. However, the referees are mistaken if they assume that the connection between everyday and specialized scientific terminology exists a priori and is not created in the classroom.⁵ We consider it incorrect to declare the assertion everyday term ›heat‹ = specialized scientific term heat as absolute and then ›identify‹ a fundamental mistake on this basis.

The commentaries about thermodynamics in the DPG report are to be found under the titles *Temperature equilibration*, *Expansion of a gas into a vacuum* and *Conductivity of entropy*. We will begin with the first and last of these three points because they relate closely to each other.

3.1 Temperature Equilibration

The referees make a special demand of the KPC. We would normally expect a first introduction to the simplest thermal phenomena on the first pages of a textbook (as it is done on page 7 of Herrmann, 2010b). In contrast, the referees demand that these phenomena must be completely explained right there: ›If entropy has to be introduced already, as is done in the KPC—which in this case constitutes a complication—it is necessary to explain its role in natural processes correctly and completely. The KPC does not do this.‹

This excessive demand contradicts the basic assumptions underlying any successful elementary exposition. Beyond this, the statement is false because the relationship between entropy transfer and energy transfer is explained a couple of pages later in Section 1.10 on page 17. Entropy generation in heat transfer is explained in Section 1.11 on page 19.

How should this criticism be understood? Are the referees actually accusing the KPC of dedicating too much space (i.e., 12 pages) to introducing all the phenomena of heat transfer and introducing all the quantities which are necessary to a quantitative description?

3.2 Conductivity of Entropy

The referees are of the opinion that the concept of entropy conductivity is unsound because more entropy flows into the cold end of a conductor than is released at the hot end. However, it should be noted that the amount of entropy flowing away is, in fact, proportional to the temperature difference ΔT , whereas the amount of entropy produced is proportional to ΔT^2 . In any case, the process of heat conduction can only

⁵In everyday life, when the word ›force‹ is used, often it is used in terms closer to ›power‹ or ›energy‹ rather than force in mechanics.

be described for small enough ΔT by a linear relation between ΔT and the entropy current I_S , or the energy current I_E , respectively. This implies that nonlinear contributions given by $\sigma_S(T) = \lambda(T)/T$, where $\lambda(T)$ is the conventional conductivity defined in terms of the energy current, must be negligible. The proportionality between $\sigma_S(T)$ and $\lambda(T)$ is justified by the equation $I_E = T \cdot I_S$ (Eq. 10 in Section 1.10) for the relation between the energy current and entropy current on surfaces with constant temperature. For this reason, the concept of entropy conductivity easily agrees with the conventional heat conductivity as defined by Fourier's law.

3.3 Expansion of a gas into a vacuum

The referees object to the description of irreversible expansion of a (not necessarily ideal) gas into a vacuum in Section 2.7. This is based upon the way the referees chose to interpret the observations on page 41 of the KPC

1. When entropy is added to a gas, its temperature rises,
2. when a gas is expanded at constant entropy, the temperature decreases.

as relating directly to the process of free expansion into a vacuum. This is nowhere to be found in the KPC text. The authors of the KPC only remind readers at this point about well-known characteristics of gases in order to justify possible expectations for the experimental result.⁶ In order to avoid the complications that arise with this process in reality, only the starting and end states before and after expansion are considered. Instead of considering the complicated and difficult to describe process of irreversible expansion, the KPC authors have replaced the actual process by two consecutive reversible ersatz processes. These processes are an isentropic expansion while performing work and an isochoric heating in which the same amount of energy withdrawn during the first process is fed back from a heat reservoir along with the corresponding amount of entropy. Crucial to the conclusions drawn from this that the temperature of an (ideal) gas undergoing an irreversible process is the same in its initial and final status, is the fact that the starting and end states of the gases in the real and reversible ersatz processes are identical. This fact justifies the statement in the KPC that »Both effects cancel each other out.«

Authors of conventional textbooks call such an approach the only possible one (compare [Nolting, 2005](#), p. 179, for example), because the traditional representation of thermodynamics tells us that only reversible processes can be dealt with quantitatively. This is because in the case of irreversible processes, changes of entropy are different than the sum of en-

trophy flowing in and flowing out. Why should this approach, which is found in conventional textbooks, be inadmissible for the authors of the KPC?

The reviewers write: »The attempt by the KPC to center thermodynamics solely around entropy and temperature must be viewed as physically mistaken and leading to false conclusions. It equates two different physical quantities thereby making an elementary mistake. Putting the fundamentally wrong identification of entropy and heat at the beginning, immediately leads to contradictions. As the examples above have shown, the authors themselves have fallen for this as can be seen in their description of expansion of an ideal gas in a vacuum. How can this approach be easier for school pupils to understand? Whereas the physically correct explanation of entropy as the quantity deciding about the course of irreversible processes and denoting the number of states a system can take, is missing, the KPC introduces entropy as a complication at a point where the concept of quantity of heat would suffice.« The referees have proved wrong statements that are either not in the KPC text or are scientifically correct, and then they admonish the lack of important statements in the text that are actually there.

4 Magnetic Charge and the Concept of Vacuum in Electrodynamics

4.1 Magnetic Charge

The referees write »Paul Dirac speculated that magnetic charges and a magnetic monopole could exist as elementary particles. The existence of magnetic charge would eliminate the asymmetry between the electric field and the magnetic flux density in Maxwell's equations. Despite intensive effort, it has not been possible to experimentally prove the existence of isolated magnetic charges. Contrary to this experimentally proven fact, which is acknowledged in the teaching manual for electrodynamics (p. 15) of KPC [2],⁷ the KPC assumes in the textbook for secondary level 2, Volume 1, Electrodynamics [3]⁸ the existence of magnetic charge (p. 41).«

This passage is doubly surprising because:

1. One can hardly claim that the non-existence of magnetic monopoles can be experimentally verified. This goes against the general and basic epistemological position of empiric science which states that the non-existence of an experimental finding can be falsified, but never verified.
2. The referees assume that the objects called ›magnetic charge‹ by the KPC are magnetic monopoles. This is explicitly contrary to the actual text in the KPC where

⁶The gas in the first container expands approximately adiabatically and initially cools down while the gas flowing into the originally empty second container is adiabatically compressed and initially warms up until the process of heat conduction leads to a temperature equilibrium between the two containers. Only this common end temperature can be compared to the starting temperature.

⁷Herrmann (2002).

⁸Herrmann (2010a).

it is stated that: »**The total magnetic charge of a magnet is zero** [emphasis in the original]. This differs from electric charge. A body can be given a [...] small electric net charge. This difference between an electric charge and a magnetic charge is very important. It means that there are electric currents (flowing electric charge) but no magnetic currents (flowing magnetic charge).« Obviously, the authors of the KPC find it very important for the readers to avoid exactly the misconception that magnetic charge is identical to magnetic monopoles and to make the reader aware of the central difference between freely moving electric charge and bound magnetic charge. Nevertheless, the reviewers again conclude that: »The obvious experiment for this is to saw a bar magnet into two parts (compare Fig. 6). As we know, doing this produces two new bar magnets and no isolated charge. This is not an isolated case but as already stated above, the search for magnetic monopoles has remained unsuccessful. Therefore, there is no experimental justification for magnetic charges up to today.«

These statements stand in opposition to the ones in highly regarded classical textbooks. One example is in the new edition of Gerthsen's textbooks by one of the referees (Meschede, 2006, p. 363): »There are certain cases where it would seem obvious that the image of spatially concentrated ›magnetic charge‹ should be used. In the case of long solenoids or bar magnets (length l), point-like ›magnetic charges‹ or pole strengths $\pm P$ could be attached to pole shoes where almost all \vec{B} -lines converge or diverge, so that the magnetic moment of the solenoid or bar is given by $\mu = Pl$.«

It is therefore even more surprising that the DPG report continues with the following statement: »The question is not whether magnetic charge exists or not, but whether introducing it serves any purpose. This is an argument that completely discredits the KPC in the eyes of serious scientists. It is an obvious example of how the KPC bends fundamental physical facts to fit didactic convictions.« Again, statements in the KPC are said to be wrong or misleading, even when similar statements can be found in established conventional textbooks. If the text (Herrmann, 2010a, pp. 41) is looked at with unprejudiced eyes, it is obvious that the KPC authors are talking about magnetic surface charges as is done in conventional textbooks (Meschede, 2006, Jackson, 1975) and not magnetic monopoles.

This is said explicitly in the KPC-text in the sentence preceding the criticized one: »Magnetic surface charges on a permanent magnet can be introduced by analogy with bound electric charges on the surface of a polarized dielectric material« (Herrmann, 2002).

The referees continue: »The referees of the DPG are of the opinion that even in schools only experimentally provable facts may

be taught for which a didactic method must be found and that physical ›facts‹ may not be invented so that a didactic method appears more elegant.« We consider that this statement can be agreed upon and that it is generally shared. However, up to this point (and beyond), proof that the KPC authors have invented experimental facts is missing.

4.2 The Technical Addendum to the Report: On the Question of Sources of the \vec{H} -Field

In their addendum to the report, the authors—in a puzzling and surprising contradiction to their own report—dedicate several pages to explain things that are seen in exactly the same way by the KPC, namely, that the sources of the \vec{H} -field are sinks of magnetization \vec{M} . However, the authors rigidly stand by their view that the magnetic charges described in the KPC are the magnetic monopoles in the Dirac sense. Even when considered in a charitable light, this view is a clear misleading. This can be clearly seen in F. Herrmann's lecture notes⁹ where magnetic and electric quantities are related to each other and where ›magnetic phantom charges‹ at the ends of a magnet are explicitly discussed. Even more clearly: the author adds that the analog electric charge density on the magnetic side should be set equal to zero »because free magnetic charge does not exist« (page 52 below).

As the referees conclude in their addendum, it is just as possible to describe the \vec{B} -field of a permanent magnet by Ampere's molecular currents, namely the bound (electric) surface currents $\mu_0 \text{rot } \vec{M}$. This yields exactly the same relations between \vec{B} , \vec{H} and \vec{M} , as the (also bound) magnetic surface charges that the KPC uses in its description. The latter are perfectly analogous to the polarization charges bound to surfaces that occur in conjunction with dielectric media. Again, there is an example in which two different explanations (magnetic surface charges vs. electric surface currents) lead to exactly the same phenomenology and cannot therefore be experimentally distinguished. A disadvantage of electric surface currents is that the magnetic field of permanent magnets are usually created by electron spins, which, as we well know, cannot be explained by orbital motion of an electric charge.

4.3 Ether / Vacuum

The DPG report of this section begins as follows: »The KPC asks the question ([4]¹⁰, p.46): ›What does the electromagnetic wave actually travel through? Who or what functions here as the carrier?‹ Although, starting with Fizeau's experiments and then those of Michelson and Morley, modern physics has excluded the possibility of such a carrier, the KPC continues ([4], p.46): ›After this [apparently after these experiments (comment by the referees)] it [the carrier (comment by the ref-

⁹ <http://www.physikdidaktik.uni-karlsruhe.de/skripten> (19th April 2013).

¹⁰ Herrmann (2010c)

erees)] was given a different name, because the word ether brought up too many obsolete images. This new name is 'vacuum,' in English, 'emptiness.' The carrier of electromagnetic waves is called 'vacuum' [...] If one says that in a region of space, a vacuum can be found, it means that although there is no chemical matter to be found there, something else is—namely the carrier of electromagnetic waves. As long as no wave travels through the vacuum, the vacuum is said to be in its 'ground state.'«

The KPC authors clearly state here that the word ether is connected to antiquated ideas that they do not share. Nonetheless, the referees accuse them of an antiquated understanding, namely that the word ›carrier‹ means the same as the term ›ether‹ which stems from the early 20th century. We find this accusation to be unfair because in the next passage, the KPC authors write »People used to think that light was a mechanical wave in this ether which makes the carrier move, exactly like the air moves as the result of sound waves.« The KPC authors have clearly distanced themselves from the ether model that has long been disposed of. Irregardless, the referees continue with their comments: »The KPC argues that although the word ether was eliminated as a consequence of the experiments, electromagnetic waves still have a carrier medium (similar to sound waves). When so expressed, it causes misleading, if not false ideas.«

In our opinion, the KPC authors have been wrongly accused of saying that electromagnetic waves have a carrier of the same type as the one sound waves have.

It is remarkable that the referees then write: »They [electromagnetic waves, comment by the authors] do not need the ether or the vacuum as a carrier medium,« but then already relativize their conviction in the next sentence: »In fact, based upon quantum theory, the vacuum can be considered a modern successor to the ether.« The KPC states exactly this on page 46. The referees continue to clarify: »However, a decisive difference to the classical ether is that the vacuum of quantum field theory is Lorentz invariant so that it satisfies the theory of relativity and does not single out a reference system.« This is without a doubt, correct. Correspondingly, nowhere in the KPC do we find the statement that the carrier medium discussed there would single out a reference system. How could a vacuum single out a reference system?

The referees' thesis that »The examples given here show that, according to the present state of scientific knowledge, the KPC makes false statements (the existence of magnetic charge or monopoles) or creates false images by imprecise formulations (vacuum)« cannot be documented by texts in the KPC.

5 Compatibility

The question of compatibility is an important one that should be discussed. Unfortunately, although the referees asked the

question, they only answered it in a very limited way: »It is the task of physics teaching to represent the current state of physics so that students can understand the phenomena of nature and technical devices. [...] To do so, school physics must hold to the national and international terminology in use today that has made the dialog both inside and outside the world of physics possible and has also stood the test of time when checked against experiments. The momentum current of the KPC does not fulfill these requirements as its terminology is not found in nationally and internationally disseminated common books for students of physics. Just a look at the index in various textbooks proves this. For example, in the textbook Gerthsen Physics [6], the term force is referred to 14 times and momentum current is not mentioned at all.«

After negating the scientific relevance of ›momentum current‹ in great detail, the DPG report then limits itself to stating which terminology is in general use. Counting index entries seems an insufficient method for determining which terms are shared by the scientific community, and to what extent. Even if it came to using these findings as a reason to accept or reject a term, we would like point out that the 23rd edition of Gerthsen (Meschede, 2006) uses the concept of momentum current several times in the body of the text (p. 171 and p. 239). In other words, it appears that this term which is completely identical with the term force, is compatible with more conventional descriptions in physics. Other reputable texts use this term as well—in Landau and Lifschitz (1991) the term ›momentum current density‹ even appears in the otherwise very short index.

Regarding the referees' criticism of introducing units that are not generally used in physics, we agree. Even though the developers of the KPC consider them useful, we believe that the potential problems of communication resulting from them should be avoided.

A much more important question, however, is what the advantages and disadvantages are for pupils who have been taught according to the KPC before they begin a further education and later enter into their professional lives. In discussions about the KPC, it is often said that pupils and students who have been taught according to the KPC cannot participate as equals in discourse about subjects in the natural sciences because they have only marginally learned and practiced concepts such as ›force‹. The term momentum current is said to be unusual in everyday life.

At first glance, this rings true. However, it is also true that the concept of force—as introduced by other approaches and as understood by experts—is associated with the intended images only by a minority of students. According to investigations of this topic, general ideas about ›force‹ are very close to those of ›energy‹, ›vitality‹ or ›motion‹. It is important to realize that when the word ›force‹ is used in everyday life as well as in popular scientific literature, the partner in communication will in many cases activate varied colorful images

and very little will comply with the intentions of physics education.

Just because there are problems of understanding connected with the term force, it should not be assumed that momentum current is any better without first having significant empirical investigations to support this. Such investigations should inform us about what pupils and students who have received the KPC and those who have learned mechanics in another way experience later on in their studies and working lives.

In regard to ensuring the compatibility of the KPC, we would ask its developers to comply with certain things. We consider a statement like »*The name momentum current for the quantity F has existed since the beginning of the last century. However, the name force for the quantity F is still widely in use today and is found much more often than the name momentum current*« (Herrmann, 2010d, p. 32) not to be helpful for reaching this goal. We consider this an attempt to decide which term, »force« or »momentum current«, is the one of the future. Just as we criticized the referees for doing this, which led to counting words in glossaries, we also criticize the KPC authors for attempting to decide which term should be used preferably by the scientific community.

6 Summary Assessment Concerning the DPG Report

Of course, the scientific questions raised in the DPG report and the question of compatibility are legitimate ones. We hope that these have been answered here and that it can be seen *that the basic ideas of KPC are scientifically correct and the criticisms of the referees are unfounded.*

As to the question of compatibility, we are convinced that this can only be answered by systematic credible empirical investigations. We consider the arguments in the report to be too superficial. In the following, we wish to make some comments about how the KPC is perceived by physics didactics and in physics.

7 Addendum: The Karlsruhe Physics Course Competing With Other Approaches of Physics Didactics

Discussions about the Karlsruhe Physics Course over the last three decades have always shown that it is considered exotic. At this point, we will venture an opinion as to where this might come from.

The developers of the KPC have followed a very well founded concept. It is the idea of the flow of physical quantities. The mechanics course for the secondary school level logically be-

gins with an introduction to momentum as a substance-like quantity (Herrmann, 1995, pp. 25). The text discusses the characteristics of this quantity, which is new to the students, in relation to the quantities velocity and mass of bodies. All this is embedded in a series of simple examples from everyday life. Only on page 39, is the concept of momentum current introduced and then, on page 40, it is identified as synonymous to the word force.¹¹ The decision by the developers of KPC to use flows of quantities as their central theme requires a certain chronology for introducing its terminology. In some sense, this chronology also maps onto the hierarchy of terminology according to which the course operates—basic concepts are introduced earlier than the ones that are derived from them. Momentum appears as a basic term upon which later considerations of mechanics are built. The decision for a certain governing design idea induces a specific hierarchy of terminology, a specific order to the terminology, but it does *not mean that new physical quantities were invented.*¹² The (illegitimate) equating of the perceived newness of terminology with a newness of order of old terminology appears to us to be a major source of misunderstandings.

It should be emphasized that the decision for a certain governing idea necessitates—for every concept—a chronology for introducing terminology for each one and each one will lead to its own order of concepts. To clarify this, we will use the concept for mechanics whose basic ideas were formulated by Walter Jung in the 1970s and further developed by H. Wiesner and his colleagues at the LMU Munich in the 1990s (compare among others, Wiesner, 1994, Wodzinski & Wiesner, 1994a, Wodzinski & Wiesner, 1994b, Wodzinski & Wiesner, 1994c). Today it exists, in adapted form, as a textbook for schools (M. Hopf, T. Wilhelm, C. Waltner, V. Tobias, H. Wiesner).¹³ The developers of this concept use the idea that motion cannot be physically described as a whole (as terms such as »circular motion« and »motion along a straight line« unfortunately suggest) but only pointwise. A further central idea is that of the interaction of bodies which makes itself felt when a change to direction or speed (absolute value of velocity) is observed. These ideas require that the concept emphasizes the term direction, which assumes a vectorial concept of velocity right from the beginning (differently than many conventional concepts as well as the KPC), and introduces an, at first sight, unusual definitional relation between force, mass, change of velocity, and period of interaction: $\vec{F} \cdot \Delta t = m \cdot \Delta \vec{v}$. Here as well, no new terminology, let alone any new physics, is being produced, but »only« a certain order to the terminology.

Different conceptual orders as they are developed in different didactic designs, lead to different priorities in teaching and differ in their usefulness for describing domains of phenom-

¹¹Introducing the new term »momentum current« mitigates the problem of polysemy which always emerges when terms of everyday life (»force«) are given new meanings in physics.

¹²It must be noted that the introduction of new units like Huygens or Carnot should not be mistaken for introducing new basic terminology.

¹³The textbook (german) can be downloaded from http://www.thomas.wilhelm.net/Mechanikbuch_Druckversion.pdf (19th April 2013)

ena. Each one can counteract in its own way the everyday concepts that hinder learning. If an approach should be tested for its appropriateness for schools, different questions need to be asked concerning its effect: How should the quality of the knowledge gained in class be rated? What valuation of and attitude toward the science of physics is promoted by the approach? How much does it encourage the development of motivation and interest? To what extent are the everyday concepts that hinder learning replaced by those that can easily be connected to science?

The competition between differing didactic approaches is a competition on many levels that can only convincingly take place through intensive empirical work. The reflexive response of rejecting the unfamiliar and using one's personal experiences as a student as a reference for what is or is not appropriate to teaching, does not lead anywhere—especially not when university teachers who have always belonged to the minority (!) of people who have grasped physics despite all the shortcomings and contradictions involved teaching and learning physics at school, exhibit this reflex.

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