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Symbol and Physical Knowledge

On the Conceptual Structure of Physics

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8. Idealizations in Physics*

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Heinrich Hertz was the first to introduce the concept of a symbol to characterize physical knowledge. He invoked this concept to highlight the fact that physical theories are not mere copies of nature. They contain a considerable *constructive* element. As it will turn out the use of idealizations sustains Hertz's claim.

1 An Example of an Idealization

Let us start with an example of an idealization in physics. Assume that we are interested in the question of with what velocity, v, a stone, s, descends in a medium, m, with known viscosity, η. Let us furthermore assume that the stone has an uneven surface. What one usually does in order to solve this problem is to treat the stone as though it were spherical. The stone's actual shape is replaced by a fictitious shape. This is a *conscious* and *voluntary replacement*. It is conscious because we know that the actual shape is not spherical. It is voluntary because we could go on trying to find out the velocity of the stone without replacing its shape – even if this might be more difficult. The replacement allows for an easy calculation of the velocity. We can now calculate the stone's velocity with the help of Stokes' law:

$$F = 6\pi v\eta \Leftrightarrow v = F/6\pi\eta$$

where F is the gravitational force. What we have is illustrated in Fig. 1. The real shape of the stone is replaced by the idealized shape so as to make Stokes' law applicable to it.

2 The Concept of an Idealization

The simple example above allows us to point to three distinctive features of idealizations. First, idealizations are replacements. For reasons that will become clear later on I will be fairly liberal at this point and will allow replacements not only of mathematical descriptions but also of physical systems and data. Thus I take idealizations to be *replacements of either mathematical*

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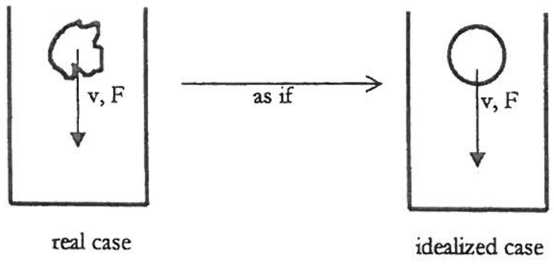

Fig. 1.

descriptions, physical systems or data. Second, these replacements are both *conscious* and *voluntary*, i.e., the physicists who idealize have to be conscious of the fact that they idealize. For this reason hypotheses that turn out to be wrong do not count as idealizations. When Galileo proposed his law of free fall, he did not know that his law was wrong. He believed it to be correct. If, however, nowadays a physicist makes use of Galileo's law instead of the correct law based on Newton's or Einstein's theory of gravitation, this has to be classified as an idealization. A hypothesis may *turn out to be wrong*; an idealization is *known to be wrong* (if it concerns theoretical assumptions). It is due to this second aspect of idealizations that the resultant physical theories can be qualified as symbols in the sense of Hertz. Idealizations introduce a constructive element into physical knowledge that is not forced on us by nature. A third characteristic feature of idealizations is that the replacement is not undertaken arbitrarily. The replacement is considered to be *more optimal* in some sense that we have to specify. The focus of the second half of this paper is on the rationale for idealizations and will thus explicate in what sense idealized physical systems, data or descriptions are more optimal than those they replaced.

3 Different Kinds of Idealization

In this section I intend to distinguish various kinds of idealizations that play a role in physical practice. I will start with two kinds of idealizations that physicists will probably refrain from calling idealizations. However, it will turn out eventually that these procedures are closely related to others that are commonly called by this name.

3.1 Production of Physical Systems

Very often the physical systems under investigation are artifacts. They are not part of unmanipulated nature but have rather been produced in factories. Let me quote from an article in which Zeller and Pohl presented the results of

measurements of the specific heat and the thermal conductivity of amorphous solids – a case we will investigate in more detail. A table lists the samples that were used in the investigation. For every such entry not only the mass density and the molecular weight is mentioned but also its supplier. The table also tells us how these samples were produced. With respect to one sample it says:

> "The germania sample was melted at 1250°C in vacuum in a Pt crucible, kept at that temperature for 18 h in oxygen at 1 atm, rapidly cooled to 600°C and then slowly to room temperature." (Zeller and Pohl, 1973, p. 2034)

The production of physical systems is an idealization because nature is consciously and voluntarily replaced by artifacts. In what sense artifacts are more optimal than nature will be discussed later.

3.2 Isolation

Physicists typically try to isolate the physical systems they are performing measurements on. Thus the measurement of the specific heat of an amorphous solid takes place in a cryostat. The cryostat is meant to prevent energy exchange between the system and the environment in the low-temperature region. In high-energy physics shielding off unwanted particles plays an important role. E. McMullin has called this procedure "causal idealization":

> "The move from the complexity of Nature to the specially contrived order of the experiment is a form of idealization. The diversity of causes found in Nature is reduced and made manageable. The influence of impediments, *i. e.* causal factors which affect the process under study in ways not at present of interest, is eliminated or lessened sufficiently that it may be ignored." (McMullin, 1985, p. 265)

Isolation is an idealization because a situation in which various causal factors influence the system under investigation is replaced by a situation where no such external factors are present (or less factors). What I presuppose in classifying both production and isolation as idealizations is that physics is a *natural* science, i.e., that it is supposed to deal with natural objects rather than with artifacts. Otherwise these procedures could not be taken to be replacements.

Measurements provide us with data, and it is with respect to data that two further kinds of idealizations need to be mentioned.

3.3 Data Interpolation

Data are typically represented either in tables or graphically as in the following example of the specific heat of various substances (Fig. 2).

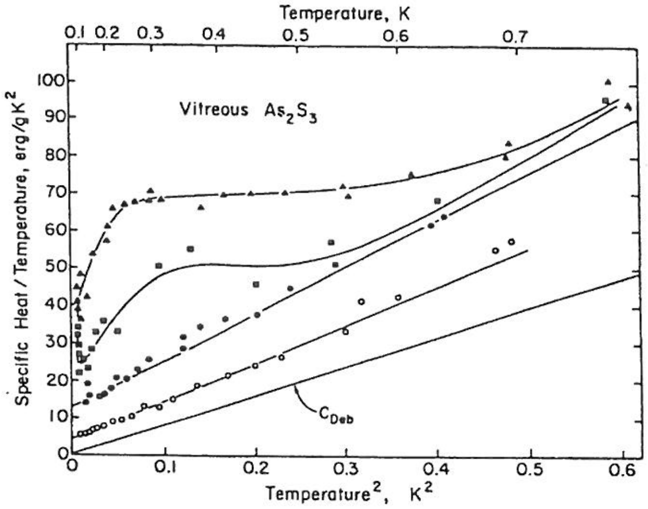

Fig. 2.

The figure is taken from Pohl (1981).

Idealizations come into play because the points that represent the results of measurements are replaced. Duhem has already pointed to the fact that typically a finite number of points is replaced by an infinite number by drawing a curve through the measurement points (Duhem, 1954, Chap. 9). This is what I call *data interpolation.*

3.4 Data Fitting

In general not all of the points that represent measurement results lie exactly on the curve. It is not these points that finally count as the representation of the behaviour of the physical system under investigation. It is rather the curve that is taken to be the phenomenological law. The curve is not meant to capture the exact measurement results. Rather, the interpolation concerns the measurement results and their associated error bars. The error bars are introduced to take into account noise in the data and certain kinds of systematic errors. I call this procedure *data fitting.* Data fitting is an idealization because it involves the replacement of the bare measurement-results by measurement results with error bars.

The phenomenological laws such as those for the thermal conductivity and the specific heat of amorphous solids stand in need of explanation. One would like to know why the behaviour of these systems deviates from ordinary solids. The essential step in the explanation is the construction of a model that can be represented as a Hamiltonian. It is here that two important kinds of idealization are situated.

3.5 Abstraction

Amorphous solids are usually taken to consist of various subsystems: the crystalline structure, electrons and so-called tunneling systems that are responsible for the deviating behaviour of amorphous solids in the low-temperature region. In calculating the contributions of each of these subsystems to the thermal conductivity or to the specific heat, it is assumed that these subsystems are isolated. The crystalline structure's contribution to the specific heat is calculated without taking into account the presence of the other subsystems. That is, the behaviour of the crystalline structure is described in abstraction. The specific heat contribution of the tunneling systems – i.e., its behaviour – is calculated in abstraction as well. The amorphous solid is thus split up conceptually into various subsystems that are treated completely separately from each other. All of these subsystems are described as though they were isolated even though in reality they are part of the amorphous solid and therefore not isolated.

Abstraction is an idealization because the subsystems of a complex physical system are treated as though they were isolated. The description of a subsystem as part of the compound system is replaced by a description of a subsystem that is considered to be isolated. It is assumed that its behaviour can be calculated as though the others were not present (in the absence of interaction).

It should be added that the behaviour of the complex system is usually determined by adding up the contributions of the various subsystems and by taking into account interactions if they occur. It also sometimes happens that not all subsystems of a compound system are taken into account. These are then treated as disturbing factors.

In contradistinction to isolation or causal idealization (Sect. 3.2) abstraction is a purely theoretical procedure, whereas isolation or causal idealization is an operation on physical systems.

3.6 Idealization in the Narrow Sense

It is *idealizations in the narrow sense* which physicists very often have in mind when they employ the concept of idealization: a property of a physical system is replaced by another property that the system is known not to have. Our simple example of an idealization at the outset is an example of an idealization in the narrow sense. Another typical example that plays a role in various areas in physics is the introduction of periodic boundary conditions. In one textbook for solid-state physics we read:

> "A more satisfactory choice is to emphasize the inconsequence of the surface by disposing of it altogether. We can do this by imagining each face of the cube to be joined to the face opposite it, so that an electron coming to the surface is not reflected back in, but leaves the metal, simultaneously reentering at a corresponding point

on the opposite surface. Thus, if our metal were one-dimensional, we would simply replace the line from 0 to L to which the electrons were confined, by a circle of circumference L." (Ashroft and Mermin, 1976, p. 33).

Idealization in the narrow sense is idealization (in the wider sense) because the description of a physical system instantiating some property is replaced by another description of the physical system instantiating another property.

After the construction of a model and the corresponding Hamiltonian, it is in general possible to calculate the physical magnitudes that the system in question ought to have on the assumption that the model is a good model. In the course of this, two kinds of idealization may occur.

3.7 Neglect

Given a certain model, in the course of the calculation certain approximations occur. A typical case of neglect occurs when one has to deal with Taylor expansions. Terms of third or higher order tend to be neglected by physicists.[1] Neglect is an idealization because one mathematical function is replaced by another mathematical function.

3.8 Simplification

A similar kind of idealization occurs when, for Example, in the course of the calculation of a physical magnitude a summation is replaced by an integration. This kind of simplification is an idealization because, as in the case above, one mathematical function is replaced by another mathematical function.

The main point of this list of idealizations is not to claim that it is exhaustive or that all of these various kinds can be distinguished by clear criteria, for example, in the case of simplification and neglect. The aim is rather to give an overview of the scope of procedures that play a role in physical practice. As I have already mentioned, I have been fairly liberal in admitting certain procedures as idealizations that are not usually called so. In what follows I will take those idealizations that are uncontroversially categorized as such as my empirical basis so to speak. Every account of idealizations has to make clear why physicists make use of them. It is *theoretical idealizations* that I take to be uncontroversial idealizations, namely, idealization in the narrow sense, abstraction, neglect and simplification. I will not argue for this classification and take it to be evident. A successful account of idealizations has to give a rationale for all of these procedures. In what follows it will turn

[1] Of course in general there are good reasons why certain contributions, e.g. in perturbation expansions, can be neglected. This is, however, not what we are interested in at this point. (See Sects. 5.2 and 5.3 for the relation of empirical adequacy and idealizations.

out that such an account will be able to explain the other procedures I have included too.

4 Mathematical Simplicity

With regard to the *theoretical* idealizations, i.e., simplification, neglect, idealization in the narrow sense and abstraction, it is not difficult to provide a provisional rationale for their employment. These procedures lead to simple theories, and they allow for a simple mathematical treatment of the problems in question. Thus the authors of a textbook on solid-state physics – Ashcroft and Mermin – comment on the assumption of a quadratic potential:

> "[it] is not made out of strong conviction in its general validity, but on grounds of analytical necessity. It leads to a simple theory – the *harmonic approximation* – from which precise quantitative results can be extracted."[2]

Similarly in a book on phase transitions the author – Goldenfeld – comments on the use of models:

> "The casual reader of any textbook or research paper on phase transitions and statistical mechanics cannot help being struck by the frequency of the term 'model'. The phase transition literature is replete with models: the Ising-model, the Heisenberg-model, the Potts-model, the Baxter-model, the F-model and even such unlikely sounding names as the non-linear sigma model! These 'models' are often systems for which it is possible (perhaps only in some limit or special dimension) to compute the partition function exactly, or at least to reduce it to quadrature (i.e. one or a finite number of integrals rather than an infinite number of integrals)." (Goldenfeld, 1992, p. 32).

All of the theoretical idealizations enhance mathematical simplicity. This is evident in the cases of neglect, simplification and idealization in the narrow sense. Abstraction, however, helps simple models to be employed as well. It allows one to split up conceptually compound systems that would have needed a special treatment. The subsystems can often be described with the help of simple models.

[2] Ashcroft and Mermin (1976), p. 422. The above-mentioned procedure is – strictly speaking – not an idealization because it is not *known* to be false. It is, however, not a clear case of an hypothesis either, since it is not invoked because it is assumed to be true.

5 Idealization and Reality

What has been said so far is rather uncontroversial. Controversy tends to arise as soon as one asks whether idealizations and mathematical simplicity lead to faithful representations of reality. Rom Harré has distinguished two approaches to this question, those of Galileo and of Nancy Cartwright.

> "In Galileo's ontology the methodology of idealizations, expressed in the theorems of geometry, represents actual structures and processes which are the core of reality. (...) On the contrary Cartwright argues that just because the laws of nature express idealizations they cannot be true of the real world. And they express idealization because they are descriptions of idealized models of reality, not messy old world itself." (Harré, 1989, p. 190).

So what we have is two theses, two rationales for the employment of idealizations. According to the Galilean account of idealizations, we invoke these procedures and thereby achieve mathematical simplicity in order to represent reality faithfully. So the ultimate rationale for idealizations is that they lead to a true description of the world. Cartwright argues that idealizations lead us away from truth. In using them we aim at other epistemic values such as explanatory power. Explanatory power and truth do not pull in the same direction in all cases. The rationale for idealizations is that we aim at explanatory power because explanatory power is enhanced by mathematical simplicity (more details below). In those cases where truth and explanatory power move apart, we thus employ idealizations, even though they lead away from a faithful description of reality.

I will argue that neither of these positions can account for all the different kinds of idealization.

Before going into details I need to reject one popular reading of the Galilean account of idealizations.

5.1 Essentialism

One way of explicating the idea that idealizations lead to faithful descriptions is essentialism. The essentialist position has been presented by – among others – by Ellis. He observes:

> "Typically [physical theories] abstract from complex circumstances of nature, and of the imperfections of ordinary physical systems, to consider how ideal systems would behave in ideal circumstances." (Ellis, 1992, p. 265)

He then goes on to give a rationale for idealizations:

> "We do not idealize because nature is too complex to be dealt with without making simplifying assumptions, although this is no doubt true. We idealize for reasons which have to do with the basic aims of scientific research. Physical science, it will be argued, is fundamentally concerned to discover the essential natures of the kinds of things that can exist, and the kinds of changes that can take place, in a world such as ours. And to achieve its aims, science must focus on the intrinsic properties and structures of the basic kind of things and processes which are to be found existing or occurring in nature." (Ellis, 1992, p. 266)

As examples for "basic kinds of things" Ellis mentions fundametal particles, crystals and stars. It is the essential or intrinsic properties of these things that we are interested in and that we are lead to via idealizations.

> "We idealize to remove accidental properties and extraneous forces from centre stage, so we can talk about fundamental intrinsic natures of the kinds of things we are dealing with." (See Ellis 1992, p. 272.)

What essentialism says is that idealizations remove properties of physical systems which are accidental and yield a description of the essential nature of the system in question. A *fortiori* according to essentialism every single form of idealization is a move towards the essential nature of a physical system. However, this is not obvious in some of the cases presented above. Why should we believe that leaving out everything but the quadratic term in a Taylor expansion or replacing a summation by an integration leads towards the discovery of the essential nature of a physical system? At first sight it seems that we use these idealizations for reasons of simplicity rather than for reasons of discovering essential natures. The same is true for idealizations in the narrow sense. Why should we believe that considering a solid as boundless (as in the example in Sect. 3.6) provides us with the description of an essential nature. What Ellis needs to substantiate his claim is an argument according to which the mathematically simpler description leads to the essential nature of a physical system.

Ellis might be tempted to argue as Galileo presumably would have. Galileo believed that the book of nature is written in mathematical language. He therefore took the idealized mathematical description of nature to be the correct description of nature. This is, however, not the problem we have to deal with here. What we need to answer is the question which among various kinds of *different* mathematical descriptions is most likely to be the most faithful description. What Ellis has to presuppose is not only that the book of nature is written in mathematical language but furthermore that the more simple mathematical descriptions are more likely to be true. In the next section I will present an argument to show that this claim is unwarranted. As long as there is no positive argument for such a position it seems reasonable to look for other explanations of why physicists make use of idealizations.

Ellis' position furthermore has to face a problem with abstractions, the case to which his account of idealizations seems to be most suited. This problem has to do with the employment of such concepts as *essential* and *accidental*. The following is how Ellis analyzes why we treat the crystal as though it were isolated in abstraction:

> "The crystal structure will almost certainly have flaws and contain impurities of various kinds, which the model will quite properly ignore. The model will ignore these details, because the aim of the exercise is not to save phenomena exactly, but to describe the essential nature of the processes which give rise to the phenomena observed." (Ellis, 1992, p. 276)

In the case of abstraction sometimes one of the subsystems is indeed treated as a disturbing factor and neglected altogether. This, however, is not what happens in general. In the case of a metal the contribution of the crystal and the electrons are completely on a par.

In calculating the contribution of subsystem A to a compound system's behaviour, we abstract from the contribution of subsystem B *and vice versa*. Subsystems A and B are totally on a par. Therefore this kind of idealization cannot be analyzed in terms of essential natures and accidental properties. That would presuppose that one can elevate one and only one of the subsystems of the compound system to the status of an essential nature. Abstraction, however, is completely symmetrical and does not provide the least indication for such an elevation to be legitimate.

5.2 Idealizations and Empirical Adequacy I

The criterion of empirical adequacy will help us to distinguish two classes of idealizations. Physicists make use of these classes for different reasons as will be argued for in what follows.

Let me begin with a quotation from the physicist J.L. Synge. He argues that the use of idealizations is unproblematic as long as the resulting theory is empirically adequate:

> "Approximations based on the neglect of small terms are very frequent in mathematical physics, and there is seldom any reason to object to them. One feels that if there is anything wrong, it will show up in some anomaly, and then one can revise the theory." (quoted in Laymon, 1984, p. 115)

Synge indicates that there is a tension between idealizations on the one hand and empirical adequacy on the other (presumably something will "show up in an anomaly" as an empirical *in*adequacy). One will allow for idealizations as long as the discrepancy is not too big. If the discrepancy is felt to be too large tension turns into conflict and the idealizations in question have to be revised. Whether or not a discrepancy can be tolerated is presumably a matter of pragmatic considerations.

The fact that the discrepancies between what is predicted on the basis of idealized models and the phenomena is taken to constitute a tension or in some cases even a conflict indicates that a faithful representation of nature has not been achieved. This is at least what I will presuppose in this paper: empirical inadequacy conflicting with theorizing would point to the fact that the theories or models do not represent reality adequately. It is furthermore the only criterion for unfaithful representation we have. We thus have to conclude that, as long as the tension does not amount to a conflict, those idealizations that lead to mathematical simplicity are invoked *even though* they may lead to a less empirically adequate description, that is to a less faithful representation of nature than a non-idealized description.

This is particularly convincing in the case of simplification and neglect, such as the example of the expansion of the Taylor series, or in the case of idealizations in the narrow sense, such as the case of the boundless solid.

Those idealizations that lead to mathematical simplicity allow simple models to be applied in more cases than in a situation where empirical adequacy were the only thing physicists were interested in.

These idealizations describe physical systems as if they would fall within the range of those simple models that allow for explicit calculation of physical magnitudes. They widen the models' range of application. This is the position Nancy Cartwright advocates in her *How the Laws of Physics Lie*:

> "The aim is to cover a wide variety of different phenomena with a small number of principles [...]. It is no theory that needs a new Hamiltonian for each new physical circumstance. The explanatory power of quantum theory comes from its ability to deploy a small number of well-understood Hamiltonians to cover a wide range of cases. But this explanatory power has its price. If we limit the number of Hamiltonians, that is going to constrain our abilities to represent situations realistically." (Cartwright, 1983, p. 139)

To conclude: We have a rationale for the application of some of the above-mentioned procedures. Idealization in the narrow sense, neglect and simplification allow simple models to be applied to the physical systems. The range of application of these models is enlarged. The fact that a discrepancy between the predictions on the basis of these models and actual measurements is felt to be a tension indicates that Cartwright is right in analyzing these procedures as leading away from the true description of the world.

Widening the range of application of simple models can furthermore be considered to be an explanation for the procedure of data interpolation. Interpolating a certain curve is legitimate as long as no anomaly turns up, i.e., as long as there are not a lot of data far away from the curve. Data interpolation tends to favour simple phenomenological laws, as, for example, laws with integral integers. In general there are established procedures for the explanation of phenomenological laws that vary, say, with the cube of temperature. Simple phenomenological laws allow the range of application of simple models to be widened.

5.3 Idealizations and Empirical Adequacy II

The tension between empirical adequacy and some kinds of idealizations has been taken to indicate that the idealizations in question do not provide a faithful description of nature. There is, however, a kind of theoretical idealization where there is no such tension. This is the case of abstractions. Let me explain this with the help of the following example:

In a paper on amorphous solids the specific heat of amorphous nonmetallic solids has been analyzed by the author Hunklinger. Three contributions to the overall specific heat can be distinguished: the crystalline contribution (c_{Debye}), the contribution of the tunneling systems (aT) and a further contribution whose origin was not clear when the paper was written (bT^3).

> "[T]he origin of the 'excess cubic term' bT^3 is less well understood. It cannot be caused by phonons in the ordinary sense because it is known from the acoustic experiments up to 400 Ghz [...] that long wavelength phonons in amorphous solids exhibit hardly any dispersion. On the other hand it cannot be attributed to TS [Tunneling Systems, A.H.] either as we will see [...]." (Hunklinger, 1986, pp. 96–97)

With respect to the specific heat of the compound system (c_V) we thus have:

$$c_V = c_{Debye} + aT + bT^3 \quad (1)$$

The complex system at hand contains three subsystems: the crystal, the tunneling system and an unknown system. The abstraction I will discuss in what follows is this: on the one hand we consider a subsystem that is itself complex, namely the crystal plus the tunneling system, on the other the unknown system. In calculating the contribution of the crystal plus the tunneling systems, we abstract from the unknown factor. What happens if we test the predictions of our calculations? It turns out that it is empirically inadequate with respect to the physical system under investigation. The term bT^3 quantifies the amount of the empirical inadequacy of the theory of the crystal plus the tunneling systems. Our reaction towards this inadequacy is, however, not to revise the theory we have. Even in the absence of an understanding of the term bT^3 it is legitimate to apply the theory of the crystal plus the tunneling systems to the physical system at hand. Abstraction may lead to empirical inadequacy. The legitimacy of abstraction, i.e., in our case, not taking into account the third term, does not depend on whether bT^3 is small or not. There is simply no tension between abstraction and empirical adequacy as long as there is a reason to attribute the discrepancy to some kind of *further contribution* – whatever that reason might be. Therefore, in the case of abstraction, empirical inadequacy cannot be taken to indicate that representation fails as it did in the case of the above discussed idealizations.

One might object that in both cases, i.e., abstraction on the one hand, and the other theoretical idealizations on the other hand, empirical inadequacy forces us to revise our old theory or to de-idealize. This is true in a certain sense, but the remark does not take into account that the revisions or de-idealizations in the two cases have different implications with respect to the question of whether the old theory was true or a faithful representation of reality. In the case of an empirical inadequacy due to neglect, simplification or idealization in the narrow sense, the idealized (i.e., not yet de-idealized) theory or model has to be revised. It being a false description leads to empirical inadequacy that enforces a revision. In contrast, if we deal with abstractions and it turns out that our model is empirically inadequate, we do not revise the model, we rather add another factor. It turns out that the abstracted model was not the *whole* truth.

This amounts to the following: idealizations such as neglect, simplification and idealization in the narrow sense lead away from truth or a faithful representation of reality, whereas there is no reason to believe that abstraction does. It is thus reasonable to look for a rationale for abstraction in the spirit of the Galilean account.

6 A Rationale for Abstractions

Abstraction separates compound systems into subsystems and tries to understand the behaviour of the compound systems on the basis of the behaviour of these subsystems. C.D. Broad has analyzed various possible kinds of explanations that have recourse to the behaviour of their parts. What is characteristic of explanations in the natural science is what he called "mechanistic explanation" (Broad, 1925, Chap. 2). This notion of mechanistic explanation can best be reconstructed as follows:

A complex system's property can be explained mechanistically if it is – at least in principle – possible to deduce (to explain) the property on the basis of

- (i) the properties of the isolated components,
- (ii) general laws of combination and
- (iii) general laws of interaction.

I do not intend to go into the details of this characterization in this essay.[3] The main point for our investigation is that this kind of explanation requires knowledge about the components' behaviour in isolation. We need to know how the subsystems would behave if they were isolated in order to be able to explain the behaviour of complex or compound systems.

[3] For a detailed analysis see Hüttemann and Terzidis (2000).

Abstraction is a procedure that can be understood if one presupposes that physicists make use of it in order to figure out how systems (subsystems) would behave if they were isolated. Knowledge of how systems would behave in isolation is so valuable because there is a very restricted number of laws of interaction and of laws of combination, that allows to calculate all kinds of other systems' behaviour.[4]

It is not only abstraction that can be shown to be a rational procedure on the basis of this assumption. The latter also provides a rationale for why physicists are not only interested in observation but also in experimentation, i.e., in creating phenomena. "To experiment is to create, produce, refine and stabilize phenomena." (Hacking, 1983, p. 230) The best evidence for how physical systems behave if they were isolated is provided through situations in which disturbing factors are absent. The production and isolation of physical systems can be understood as the attempt to realize these conditions. This is why I mentioned these non-theoretical idealizations in the classification in first part of my paper. These procedures are invoked for the same reasons that abstractions are invoked: in order to figure out how systems would behave in the absence of disturbing factors, i.e., if they were isolated.

This rationale also plays a role in explaining data fitting (as opposed to the case of data interpolation). Data fitting is reasonable if one assumes that the deviations are due to unspecifiable disturbing factors. Disregarding these random disturbing influences results in a representation of the isolated system's behaviour.

The knowledge one gains about how the physical systems would behave in isolation, thanks to the procedures of abstraction, production, isolation and data fitting, can then be used to understand the behaviour of more complex systems.

With respect to production, isolation, data fitting and abstraction we have thus proposed a non-essentialist reading of a Galilean account of idealizations. These procedures lead to a true description of the world in so far as they help to discover those components that explain the behaviour of complex systems.

The overall result of our investigation concerning the rationale for idealizations is this: production, isolation, data fitting and abstraction are used in order discover those components that explain the behaviour of complex systems in nature. Idealization in the narrow sense, neglect, simplification and data interpolation are used in order to describe these physical systems such that they fall into the range of application of simple models. We have all reason to believe that the former procedures lead to a faithful representation of what kind of constituents there are in compound systems, whereas the latter procedures provide descriptions of these constituents in terms of simple models.

[4] In the case of quantum mechanics it is the simple tensor product rule for non-identical subsystems and its restriction to certain subspaces in the case of identical subsystems.

7 Conclusion: Idealization and Symbol

Idealizations have been defined at the outset as procedures that are invoked willingly and consciously. It is evident that model-building and the calculation of physical magnitudes are constructive activities in the sense that physicists have to decide which procedure to invoke. As has been shown above with respect to idealizations in the sense of Cartwright, there has to be found a balance between empirical adequacy and mathematical simplicity. The construction of models is certainly not determined through the results of measurements alone. Model-building is a theoretical construction process that depends on the active intervention of the physicists. Of course this does not mean that these interventions are arbitrary. As has been shown and as has been pointed out by Hertz, there are criteria that these theoretical constructs have to satisfy. In this sense idealizations in the sense of Cartwright warrant Hertz's claim that physical knowledge is symbolic.[5]

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9. Symbolizing States and Events in Quantum Mechanics

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Modern textbooks in statistical mechanics sometimes present classical and quantum-mechanical formalisms in an exactly parallel fashion. At the outset, *pure states* are symbolized by either phase space points or Hilbert space vectors (or, more generally, rays); *observables* by either real-valued functions or self-adjoint operators; and their *values* by either values of the functions or expectation values of the operators. Consequently, also time expansions of states and the values of observables have comparable expressions (see, e.g., Römer and Filk, 1994, p. 47–48). This way of parallelizing the formalisms expresses the general view that they *are* parallel in the sense that there is one set of symbols functioning in the same fashion in both classical and quantum physics, i.e., symbols describing a system's physical *state*, as well as symbols designating *observables* and their *values*.

The procedure does not, of course, intend to conceal the fundamental differences between classical and quantum physics. The classical and quantum physical states are of a fundamentally different kind, insofar as the former determine the values of *all* observables while the latter, notoriously, do not. Quantum physical states fix values only for a proper subset of meaningful observables, and they do so in principle. What they do, in addition, is to yield outcome probabilities for values of all observables. Thus, one might think in the following way: quantum-physical state vectors symbolize physical states like classical phase space points do, in the sense that they are collective symbols of fundamental system properties, but they have the additional feature of yielding probabilities for those values which they do not fix. So, it has become usual, and seems indeed appropriate, to understand the state vector as a "probabilistic system description". The important point, in terms of semantics, is that the basic descriptive function of the symbol, although only for a subset of the observables, is just the same as in the classical phase space point, but there is the *additional* feature of probability, the measurement outcome probabilities derived from the state vector by a straightforward rule of the formalism. The general view is that the fundamental difference between classical and quantum-physical formalism, wherever it is located, lies beyond this semantic parallelism of the basic symbols for system states and properties.

If this picture were altogether correct, we should expect that classical and quantum-physical formalisms, at least in a rudimentary way, start from a common "symbolic platform", before the additional probabilistic feature is brought into play in one of them. But this obviously is false. One formalism