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Why even a moderate structural realism largely eludes to be concerned with statistical thermodynamics

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abstract. Moderate ontic structural realism (mOSR) understands structures as a net of concrete, particular, and physical relations. Following mOSR the properties of fundamental objects consist in relations instead of being intrinsic properties. While quantum physics and general theory of relativity set the frame for most of the structuralist's discussions much less focus has been put on the theory of statistical thermodynamics. In this essay, I argue that in case of statistical thermodynamics the non-intrinsic view on properties might be well supported. Nevertheless, mOSR faces a severe challenge: the relational net of statistical thermodynamics consists of non-concrete and non-particular relations. The result is that mOSR is forced to untangle a fact that it once tried to object against: the problem of an occult linkage between abstract relations and concrete particular physical occurrences and events. Thus, mOSR is not able to properly describe statistical thermodynamics.[1]

1 Introduction

In recent years, structural realism (SR) has been taken as a promising account within the debate on scientific realism. Contemporary SR was introduced by Worrall's epistemic SR (Worrall 1989). Worrall argued against the so-called pessimistic meta-induction (Laudan 1981) and the famous underdetermination argument by focusing on the continuity of mathematical structures in mature scientific theories. Those structures, he claimed, are continuously preserved even across theory-change. A realist, thus, according to Worrall, should commit herself to the structural content of theories instead of making any commitment to objects – especially taken as referents of theoretical concepts within scientific theories. The further development of SR has been pushed forward by Ladyman's distinction between an epistemic and an ontic SR, famously put as "structure is all there is" (Ladyman 1998). Ontic SR (OSR) shall counter the argument that a structural realist could only gain knowledge about structural relations but non about the entities 'located' within them. As a consequence, any distinction between statements on structures and statements on entities is no longer possible (Psillos 1999, 2001). Ladyman's eliminative OSR raised a lot of severe objections, above all, how relations shall be understood if no relata are taken into account (Psillos 2006). Thus the proceeding OSR tried to modify eliminativism. Objects should now be taken as constituted by relations (Ladyman and Ross 2007, French 2010). Finally, a moderate ontic SR (mOSR) – on which I will focus in this paper – has been described, which "acknowledges objects on the same ontological footing as relations" (Esfeld 2004, Esfeld and Lam 2008, Esfeld 2013).

The ontology of quantum mechanics played a very important role concerning the development of OSR in order to clarify our understanding of the relations between structure and objects (French and Redhead 1988, French 1998, French and Ladyman 2003). The structural realist's commitment on structures instead of objects with intrinsic

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properties has been strongly supported by the phenomenon of quantum entanglement (Esfeld and Lam 2011). Looking upon the debate and the literature, one may well say that it is quantum physics and its ontology on the one hand, and general theory of relativity (GTR) on the other hand that set the frame for most of the structuralist's discussions.

Much less focus has been put on another fundamental theory in physics: the theory of thermodynamics. In this paper, thermodynamics shall be understood within the general framework of statistical physics. Statistical physics attempts to combine a micro-theory with a macro-theory in order to characterize an equilibrium state from a micro-theoretical quantum mechanical perspective (Sklar 1993, Uffink 2007, Frigg 2008). Thus, the question about reductionism arises. Is it possible to completely reduce thermodynamics to quantum mechanics? This question has not at all been answered yet (McLaughlin and Bennet 2005, Hartmann and Frigg 2010, Hartmann and Beisbart 2011). However, thermodynamics could not attract the same attention within the discussion on SR like quantum mechanics or GTR did.

In this paper, I will argue that the conception of statistical thermodynamics very well fits central ideas of mOSR. Thermodynamic properties indeed can be understood within a relational net, and they should be described as non-intrinsic properties. However, the characteristic relations within the theory do represent a separate group of relations compared to quantum physics. Central parts of statistical thermodynamics like the partition function, the equipartition law, or intensive physical values together with their justification within a so-called micro-canonical ensemble force mOSR to accept a delicate concession. Of course, the ensemble-relations indicate structures which may be understood as a set of entities $a_1 \ldots a_n$ within a framework of relations R_i, thus building a set $\{a_i, R\}$. However, neither all of the a_i's, nor the set $\{R\}$, and thus the structure as a whole, to which the moderate ontic structural realist commits herself, can be completely understood as a concrete and particular physical structure.

In order to support that argument, I will first describe the development towards an understanding of structure in mOSR. The point is to take relations to be concrete and particular structures in nature. As a second step, I will sketch the arguments which build up the theory of statistical thermodynamics based on quantum mechanics as their basic theory. Central steps are the macroscopic state, the transition to a statistic of relative probabilities, the conception of an ensemble, the equipartition law, and finally intensive properties. In doing so, I will give an argument for why thermodynamics should not be taken to be completely reducible to the underlying theory of micro-states. One point will be to describe how thermodynamics is based on two statistics of rather different kind. The second statistic is superimposed on the first, but only the first one is concerned with the basic theory of quantum mechanics. The consequences of such a two-step creation of statistics together with a statistical justification of the basic equations in thermodynamics lead to the problem – concerning mOSR – of accepting structures to be in a certain sense expanded when compared to a standard picture of structures.

Thus, a severe challenge for mOSR occurs: mOSR has to show how even non-concrete and non-particular structures can be admitted and accepted and yet still satisfy the original intentions of a moderate ontic structural realism.

2 Structure in mOSR

ESR pointed out the structural continuity of mainly mathematical structures of mature scientific theories across theory change. By changing from one theory to another as well as within any dynamical development of physical theories, sometimes very strong changes in entity-based ontology occur. On the contrary, the formal (mathematical) structures provide a much stronger continuity. They allow to be transformed into each other by embedding, partial isomorphism, or extension. Thus, in ESR the abstract mathematical structures played a central role. When it comes to the 'essence' of the objects, we cannot reach knowledge of the same kind. This is why it was called an epistemic SR. Again, ESR is confronted with Newman's argument (1928) against Russell and Carnap, according to which any abstract structure can be placed upon a set $\{a_i\}$. Combined with a ramsification of a theory, this leads to a trivial kind of empirism. Newman's argument has been re-formulated by Psillos (1999, 2001) by arguing that ESR was no longer able to distinguish between statements about relations between objects and statements about those objects themselves.

The further development of structural realism focused on the relation between relational structures on the one hand, and the entities or objects standing in those relations on the other hand. To be more precise: SR focused on the question of how properties shall be attributed to entities and whether those entities dispose a certain primitive thisness (haeccity) (French and Ladyman 2003). In a certain sense, Ladyman's ontic SR pushed forward the idea of being committed to structures by eliminating objects. His (radical) OSR drew on quantum mechanics with the central postulate of indistinguishable elementary particles. This postulate in quantum mechanics violates Leibniz's law of the identity of indiscernibles (French and Redhead 1988). A sort of "metaphysical underdetermination" between taking quantum objects as individuals and an ontology which takes them as non-individuals gives a strong hint in favor of eliminating entity-based conceptions (French and Ladyman 2003).

Such a radical and eliminative OSR very soon was confronted with the question of how to understand talk about relations without relata (Cao 2003a, Psillos 2006). Thus, the further development showed a moderate approach of OSR which has been described in different versions. Some denied to eliminate objects, but instead took them to be constituted by the relations (Ladyman and Ross 2007, French 2010). Another version takes objects and relations to be on the same ontological level, yet still the objects in question do not have any intrinsic properties. It is certain relations (quantum entanglement, space-time metrics) that characterize those objects (Esfeld 2004). Such a moderate OSR is supported if the properties of fundamental objects consist in relations (Esfeld 2009, Esfeld and Lam 2008). The relations then are the ways in which objects exist (Esfeld and Lam 2011, Esfeld and Sachse 2010).

Concerning the questions raised in this paper, two important aspects of this development towards mOSR shall be pointed out. First, contrary to any radical OSR, objects re-entered the stage. But now those objects are characterized only by use of relations, and thus the original idea of structures has changed. Worrall's proposal clearly took structures in terms of mathematical relations which lie beyond any mature scientific theory. A typical example is given by the transition from canonical Hamilton-Lagrange mechanics and Hamilton-Jacobi equations to formulations of quantum mechanics. The way from Poisson-brackets to commutators in quantum mechanics clearly describes the intended structural continuity. Note that structural continuity played a very important role in finding the principle equations of the new theory.

Especially within a synthetically understanding of theories, transformations, (partial) isomorphisms, or extended formalisms bear a lot of the burden of the continuity-thesis.

When ontic structural realists take objects – based on relations – into account, the view on structures heavily changes. Still, the most fundamental and mathematically formulated theories of physics – quantum mechanics and GTR – stay in the focus of most researches. But now a direct analysis of those theories becomes more and more the base for a structural realist's arguments. Thus, the main concern is no longer focused on the dynamics and development of scientific theories but on the attempt to reach a structural understanding and interpretation of certain theories, as well as taking the structural conception as an instrument in order to analyze those theories and their ontology. Examples for such a 'non-continuity' approach concern general relativity (Stachel 2002, Dorato 200, Bain 2006), local gauge symmetries (Lyre 2004), structural realist interpretation of quantum field theory (Saunders 2003, Cao 2003b), or quantum-gravity (Rickler, French, Saatsi 2006). Even extensions beyond physics, concerned with evolutionary biology and molecular genetics, have been described (Esfeld and Sachse 2010).

The development of mOSR, which is progressively used to analyze and describe the ontology of fundamental theories, clearly changes the understanding of structure itself. Note the difference between claiming structural continuity between different theories and claiming a structure $\{a_i, R\}$ for specific theories in order to demonstrate that characteristic properties, existence, and ontological status of these a_i is understood only by use of and through the relational set $\{R\}$. While the first case was mainly concerned with analogies in a general sense within different formalisms, the second case, in a sense, does not care too much about analogies. It is the structural setting of a theory as a whole, including the ontology of the theory's objects that comes into view. Thus, analogy with any other theory is no longer the main purpose of those interpretations. If, nevertheless, any such analogy can be shown, it is taken as a plausibility argument in favor of SR *in toto*.

Such an approach indeed makes it possible to widely ignore any actual resistance concerning the unity of quantum mechanics and GTR and not take this fact to be deficient for the OSR project as a whole. Note that despite all differences concerning ontology and interpretation a Kopenhagen-version, a Bohm-version, or a GRW-version of quantum mechanics are described in terms of structures. This clearly indicates the shift from any continuity-thesis towards an ontologically based interest in structures or structural interpretations. Thus, one may say that the project of SR has indeed changed. One basic idea – or better: hope – can be found in many of those works: the hope of finding a further theory like quantum-gravity which may provide a structural continuity with both fundamental theories of quantum mechanics and GTR (Esfeld and Lam 2012).

In sum, the 'formula' typically found in literature to describe structures, the well known $\{a_i, R\}$, refers to much more than simple mathematical structures or structural analogy. The idea to take structures mainly to represent group-theoretical relations (French 1999, French and Ladyman 2003) gradually changes in French (2006) or Ladyman (2007) until we find structures to be defined as concrete and physical relations. In Esfeld (2008) one may read: "a structure is a net of concrete physical relations between objects. Occurrences of physical relations are in the same way concrete and particular as occurrences of intrinsic properties. Metric relations between points of space-time and relations of quantum entanglement between quantum objects each are concrete and particular structures in nature, in contrast to abstract mathematical structures, which – if they exist at all – are universals". And, "the instruments of description may be taken as mathematical structures. Structural realism, as understood here, however, refers to a physical world. It is realism concerning the concrete physical structures and not realism concerning the abstract mathematical structures".

The point here is that concrete physical structures are given structures, given relations within a given concrete physical world, while mathematical structures have become only an instrument of description. The changed understanding of structure, following Esfeld, shall avoid the Newman argument. Moreover, mOSR tries to separate itself from a mathematical SR in order to avoid any debate on *ante rem* vs. *in re* SR (Psillos 2012). However, the way in which structures shall be understood has clearly changed. The typical understanding used in mOSR shall now be confronted with the theory of statistical thermodynamics. To do so, I will now describe the conceptual framework of that specific theory.

3 The conceptual framework of statistical thermodynamics

The theory of statistical thermodynamics aims to determine collective or macroscopic properties of a system composed of a great amount of particles. The collective properties shall be connected to the microscopic properties of those particles. Thus, statistical thermodynamics makes use of a well formulated theory of microscopic particles and properties. Basic principles as well as mathematical tools of statistical physics have both proven to be strikingly robust with respect to changes of the basic-theory. Thus, the classical formulations given by Boltzmann and Gibbs, though discovered without any knowledge of quantum mechanics, have been able to be used in modern physics almost without any changes (Boltzmann 1877, Gibbs 1902).

A macroscopic state now is given by a totality of quantum states or microstates which cannot be distinguished on a macroscopic scale. Such a macroscopic state can be instantiated by a huge number of different combinations of microscopic states. This is why any knowledge of a macroscopic state is attended by a certain lack of knowledge, which precisely refers to the microscopic states. Concerning a specific macroscopic parameter – volume, pressure, thermal capacity – it is virtually impossible to measure the exact states of all single particles and, thus, it is beyond any hope to reduce a macroscopic property to the equations of motion for every single particle. Note that this is not only due to the problem of huge numbers. Even phenomena which are qualitatively new may appear by interaction of a big number of particles (e.g. condensation).

In any case, we do not know the specific dynamic state of any single particle. Still, the sum of all these states has to be conform to the macroscopic parameter (I will most of the time take the energy E to be the macroscopic parameter). Those states are called the *accessible states* of the observed system relative to the fixed macroscopic parameter. In general the number of those states of a system is extraordinarily high. One of those states is the one the system really is in, yet we cannot know which one it actually is.

However, the lack of knowledge is combined with a specific microscopic knowledge. It is very important to note that every big system we treat statistically is very well understood and known from a microscopic point of view – that is in terms of quantum mechanics. The microscopic and quantum mechanical knowledge precedes warming of the system. Since all possible states of a particle are well known and given by the basic-theory, all possible states can be combined. A relative probability then gives us the probability with respect to the whole sum of possible states for a system to be found in one of these states: to do statistics means to count states.

Consequently, two different meanings of "state" have to be carefully distinguished. On the one hand, we are talking about all possible states of any single quantum-particle. On the other hand, we are talking about the state of the system as a whole. It is well known that quantum physics itself is a theory of probabilities and it comes with its own quantum-statistics. If quantum mechanics is taken to be the basic-theory for statistical thermodynamics, one kind of statistics is superimposed on another one. The first statistic is quantum-statistics, which provide us with all the possible states that we have to count. The second statistic refers to the relative probabilities and the distribution of system states with respect to a fixed macroscopic parameter.

Let us take a look onto a simple system made up of only three particles (Reif 2008). Every particle shall posses a spin value of ½, either in up-direction or in down-direction. Every particle has a magnetic moment m. If the spin is 'up', the moment m equals +m, and if the spin is 'down', the moment equals –m. Placed within an external magnetic field H, every spin-up particle has an energy of E=-mH, while every spin-down particle has en energy of E=+mH. Which overall-states are possible for a system of three such particles? The following table shall demonstrate the described situation ("+" signifies spin-up, "–" signifies spin-down).

State	Spins	Magnetic moment	Energy
1	+++	3m	-3mH
2	++-	m	-mH
3	+-+	m	-mH
4	-++	m	-mH
5	-+-	-m	mH
6	--+	-m	mH
7	+--	-m	mH
8	---	-3m	+3mH

The possible states of our three-particle system are counted by use of the basic-theory. In our simple case we have 8 possible microscopic states. Let us now choose a fixed macroscopic parameter, e.g. energy E=mH. The system can now be found in one of the following three states (numbered 5, 6, 7):

5 (- + -); 6 (- - +); 7 (+ - -)

Still, we do not know which of these possible states our system actually is in. At this very point the famous idea of Gibbs enters the stage. Instead of the system itself, an *ensemble* representing the system is considered. How shall the idea be understood that an ensemble represents a system?

Until now we worked with a system and all its possible states which are given by a basic-theory. The question then was: "in which one of those many states may the system be found"? In a certain sense, the ensemble idea turns around that question. Let us take a large number – maybe an infinite number – of systems. Each of these systems shall be equally prepared. To *prepare* a system expresses the fact that it belongs to that very class of systems which correspond to the same fixed macroscopic parameter. These many equally prepared systems now are faced by the possibility distribution of the known possible states. The question thus turns into: "how are the many systems distributed among those possible states?"

The idea of an ensemble thus changes the view onto the relation between system and possible states, and establishes the two different kinds of statistics I have mentioned. I will now turn to the question of how the two kinds of statistics interact with each other. The basic-theory of thermodynamics, quantum physics, is a statistical theory of probabilities. The function ψ(x,t) contains the entire information about a quantum system. Every observable is linked to a Hermitian operator A. The eigenvalues of such an operator are given by the equation A ϕ_{av} = a ϕ_{av}. The probability then to get a specific value by measurement is given by

$$P_{(a,t)} = \sum \left| \int \varphi^*(x)\psi(x,t)\, dx \right|^2$$

The solution of the eigenvalue-equation provides us with the possible values of an observable. If one really takes a measurement on any system, the expected result will be found with a certain probability. After an infinite number of measurements of infinite many indistinguishable equal quantum systems, a specific value will be found with a specific relative probability. I will not say anything about the well known problems of interpretation concerning the relation between a deterministic continuous equation – Schrödinger's equation – and a probability distribution. With respect to thermodynamics it is only the relation between the two statistics mentioned which is of interest. And it is indeed the very idea of ensembles which separates those two kinds of statistics from each other.

The fundamental reason for a statistical approach is the necessity to count all the possible states of a given system. To do so, a basic-theory is needed in order to provide us with those possible states. In the end, thermodynamics aim to connect the microscopic states to the macroscopic states. The probability distribution and thus the quantum statistic holds for every single particle and thus, of course, even though in an indirect manner, for the system as a whole. The distribution of states for the whole system provides us with a set of possible states for that system. Concerning the above mentioned example, those states are given by the energy E, which might be -3mH, -mH, mH, or +3mH. The statistical ensemble, however, is defined by preparation, and exists of a large number of equally prepared systems. Equally prepared here means to be fixed to one value of energy, e.g. E=mH.

Still, we do not know which state exactly our observed system is in (state 5, 6 or 7). Since preparation of the ensemble-systems is related to a fixed macroscopic parameter, the probabilities of single states are no longer important. In the above example a spin-up state, for instance, has exactly twice the probability compared to a spin-down state. Since, however, all those systems with fixed E=mH have been chosen for the ensemble, the singular specific probabilities are not taken into account anymore. The condition of fixed energy (fixed preparation-parameter) is independent of single spin probabilities. If we ask now for the statistical probability to be in one of the possible states (related to the fixed E) the second statistic is completely independent of the first statistic which gave us the single state probabilities. To choose (or create) an ensemble by taking a fixed parameter condition has to be seen as a constraint imposed on the first statistic. Thus, the fundamental preparation is a condition to produce an ensemble and separates the second from the first statistic. Having prepared an ensemble, the first statistic's probabilities are no longer relevant with respect to further work within the framework of the second statistic.

However, the challenge to find and describe the probability distribution within a given (or theoretical) ensemble is still unsolved. This challenge leads directly towards a statement, which is very often called a 'fundamental principle' of statistical physics. It can be found in every single textbook on statistical physics as the basic postulate on equal *a priori* probabilities:

> An isolated system in equilibrium can be found in every accessible state with the same degree of probability

Or, in a more technical formulation:

> Within a microcanonical ensemble, every of the g states related to an arbitrary basis of the degenerate energy space E has the same probability $p_v = 1/g$.

This postulate is indeed of central importance for all further elaboration of statistical thermodynamics. Before turning towards those further steps, I will add some remarks concerning the postulate's apriority.

The idea of an ensemble is to distribute systems among states. The basic-theory tells us how many states there are. The distributed systems are all equally prepared. They are all subject to the same fixed macroscopic restrictions. Nothing determines those external restrictions; they have to be picked out of the possible overall conditions. Only then, by choice and preparation, the ensemble is determined.

The presupposed choice is reflected within the quantum mechanical description. If a certain fixed energy E is taken as a basis to create an ensemble, the g different states at the same time give the degree of degeneration of E. The related Hamiltonian thus contains nothing in order to distinguish those g states. Consequently´, for all degenerated energy states the integral $\int \left|\varphi_{E,\upsilon}^{*}\psi_{E}\right|^{2}$is constantly equal. All of the probabilities p_υ to be in state υ are therefore the same as well, that is to say $p_\upsilon \;=\; 1/g$.

Since, however, fixing the parameter precedes the related Hamiltonian, the operator's structure may be used to support the equal distribution law, but the Hamiltonian does not justify it. It is only after the overall condition has been fixed – a necessary fixation due to empirical occurrence –, that the ensemble can be defined. Any consequences of such a fixation can thus not be taken to be a priori.

The restriction which underlies the creation of an ensemble in a certain sense terminates quantum mechanics' area of authority. At the same time the restriction opens up the further thermodynamic path using the equal distribution postulate, while ensemble properties are considered and analyzed via the second statistic. The postulate thus has to be seen as the point of intersection where the two statistics are separated from each other. The equal distribution postulate is the central sign which indicates the separation of the two different kinds of statistics, but at the same time it represents the important connection between micro- and macroscopic properties.

Let us now turn back to the further development of the thermodynamic framework. The possible states are known and counted, the ensemble of equally prepared systems is established, and the probability distribution is captured.

Two randomly chosen elements of the ensemble shall be brought into contact with each other. It does not matter which two representatives we take. The contact shall be narrowed down to weak thermal exchange. What can be said about the new system (consisting of those two representatives)?

It is easy to see that the number of particles as well as the volume of the new system is twice that of each single part. Properties which are doubled if the system itself is doubled are called *extensive* properties.

Every single ensemble-system represents the original system. Thus, per definition both sub-systems in contact are in equilibrium. Consequently any change of states by exchange of energy within subsystem A_1 faces the same change of states within subsystem A_2. Only equal portions of energy pass back and forth. Thus the balance of changes of states Ω per energy E must be the same for both subsystems.[2] The situation can be described as (equation 1):

$$\frac{\partial \ln \Omega_1(\mathrm{E}_1)}{\partial \mathrm{E}_1} = \frac{\partial \ln \Omega_2(\mathrm{E}_2)}{\partial \mathrm{E}_2}$$

Note that this equation describes a property which, in contrast to volume or number of particles, is not doubled even though the system is doubled. Moreover, the new found property describes a condition concerning the equilibrium between two systems. The non-doubled property, called an *intensive* property

$$\beta = \frac{\partial \ln \Omega}{\partial \mathrm{E}}$$

leads to a famous definition of parameter T

$$kT = \frac{1}{\beta}$$

which is called the temperature of the system. Generally, one writes:

$$\frac{1}{T} = \frac{\partial\, k \ln \Omega}{\partial\, E} = \frac{\partial S}{\partial E}$$

with S = k lnΩ where property S is the famous entropy.[3] Concerning equilibrium between two systems two conditions are thus described:

$T_1 = T_2$ und $S_1 + S_2$ = maximum.

What has happened now? The most important and crucial point is to productively use the idea of ensembles in order to describe intensive properties. Those intensive properties characterize the whole system which is represented by the ensemble. In a sense, those intensive properties are able to close the circle starting with a given system via an ensemble and back to a system's properties. Furthermore, by use of Ω and S respectively, they connect the system's macroscopic characteristics to its microscopic properties which are at the basis of all states $\Omega_{(E)}$. By use of the three extensive properties energy E, volume V, and number of particles N, with

[2] For certain mathematical reasons and because it is easier to handle sums instead of products, most of the time the logarithm ln (Ω) is used instead of $\Omega_{(E)}$

[3] The equation can also be written with the use of the partition function $Z = \sum_i e^{-\beta E_i}$. Both notations are fully analog. Then one has $\bar{E} = -\frac{1}{Z}\frac{\partial Z}{\partial \beta} = -\frac{\partial lnZ}{\partial \beta}$ and $\bar{X} = \frac{1}{\beta}\frac{\partial lnZ}{\partial X}$ with the result that, e.g. pressure p is given by: $\bar{p}dV = \frac{1}{\beta}\frac{\partial lnZ}{\partial V}dV$. I prefer the above notation here, because the states Ω vividly refer to the underlying ensemble.

$$\partial_E \, S(E,V,N) = \frac{1}{T}$$

$$\partial_V \, S(E,V,N) = \frac{p}{T}$$

$$\partial_N \, S(E,V,N) = -\frac{\mu}{T}$$

the intensive properties temperature T, pressure p, and chemical potential μ are described.

4 Objects and relations

I will now turn to the question whether the conceptual framework of statistical thermodynamics is in line with a moderate ontic structural realist's point of view. mOSR is supported, if the properties of fundamental objects consist in relations instead of being intrinsic properties. The occurrence of a physical relation thereby shall be just as concrete and particular as was any occurrence of intrinsic properties. Is this true for objects and relations within the theory of statistical thermodynamics?

One may think this question has not too much to do with statistical thermodynamics. The fundamental objects, one may argue, are of course those quantum objects which build up the overall thermodynamic system, say, a gas. Then the crucial challenge for thermodynamics is to combine a (fundamental) theory of microstates with the observed macrostates. The central question is how "an equilibrium state may be characterized from a microscopic point of view" (Frigg 2008). And is not it exactly what we achieved? Statistical thermodynamics successfully combines quantum-states to macroscopic properties. Finally, this is what the set of the three equations above expresses. Inasmuch as the basic-theory of microstates specifies the objects, those objects of course are the fundamental objects of all macrostates. Thus, the objects of quantum mechanics are the fundamental objects of thermodynamics. And as far as mOSR achieved to demonstrate the structural relations for quantum mechanics, there is no need to repeat this with reference to thermodynamics.

Such an argument takes the theory which provides us with all possible states of particles to be the fundamental theory. Even though it might accept that there are two different kinds of statistics in statistical thermodynamics, the argument is based on the claim that all features of fundamental objects and relations – presenting a structural net, of course – are somehow preserved and transmitted into that part of the theory, which is governed by the second statistic. Moreover, it presumes that within that part or 'body' of statistical thermodynamics where second statistics is used, neither a shift concerning objects, nor a shift concerning relations takes place. In other words, the argument takes the second statistic and thus the second body of the theory to be nothing else than a purely mathematical instrument.

Of course those two bodies of the theory do meet at a very central point, the equal distribution expression (or correspondingly the partition function, see note 2). The two bodies indeed stay in touch. Otherwise we could not really speak of having successfully met the original intentions. But does this really mean that all relational features of quantum mechanics are preserved and transmitted into the second body of statistical thermodynamics without any change and without any appearance of additional or even new relations? I do not think so.

Let us start with the statement on equal distribution. As I have said above, it should not be taken to be a priori. On the contrary, if it is taken to be an a priori statement, the contact with quantum mechanics is threatened and thus the intended connection to our theory of microstates gets lost.

In order to do statistics, it is necessary to count all possible states. The number of accessible states then incorporates preparation of the system. It is exactly this process of preparation which has to be understood as a basis for the idea of an ensemble, and the ensemble-idea underlies any further argumentation to build up the theory. Only by use of preparation the ensemble is (conceptually) created. Thus preparation needs quantum mechanics. At the same time, the preparation procedure is formally supported by demanding a certain structure of the Hamiltonian, namely a Hamiltonian which shows no differences with respect to the fixed preparation-property for all accessible states. The equal distribution is a result of such a non-discriminability. As a matter of course the Hamiltonian is fully positioned within a quantum mechanical description; it provides us with all the quantum-states. The Hamiltonian related to a preparation connects the rather concrete quantum mechanical description to a more abstract notion of ensembles. Cutting that connection between basic-theory and ensemble by claiming that a central feature of the ensemble shall be a priori and not be taken as a consequence of that very connection thus contradicts the intention of the theory as a whole.

This kind of bridging function between the two bodies of the theory played by preparation, creation of ensembles, and equal distribution gives point to speak of quantum mechanics as a basic-theory. To call quantum mechanics the fundamental theory of statistical thermodynamics leads to a hasty judgment in order to understand the connection in the usual sense of a hierarchy between physical theories that is often used in debates on reductionism. It may easily been overlooked that one theory might indeed necessarily draw on a basic-theory, but at the same time is not deducible from that theory in any way.

During argumentative development and formulation of statistical thermodynamics the theory, of course, draws on quantum mechanics. Quantum mechanics provide the theory with all possible states and their countability. This is the basic performance quantum mechanics has to yield, yet the description of the theory’s setup has already demonstrated the particular point at which a non-reductive connection is manifested. It is precisely the transition from first to second statistics and thus the above described point of intersection. While quantum mechanical statistic rules on one side of this point, it is the second statistic which rules on the other side of it.

One may put it as follows. Imagine for a moment that every large system of particles comes with a little dispatch note on which, by a friendly demon, the number of particles and all their possible states has been written. Then, in order to describe macroscopic properties like pressure, volume, or temperature, we would need no quantum mechanics since we would already know the possible states. But still we would still need a kind of thermodynamics since the connection between our known microscopic states and the macroscopic properties would still be left open.

Since, unfortunately, systems do not very often come with a dispatch note, quantum mechanics is a necessary basic-theory, and quantum mechanics rules up to this point: preparation, ensemble, and equal distribution. Concerning any further processing and formulation of a thermodynamic process, the states and information given by quantum mechanics are taken as material in hand. As of now, thermodynamics and the second statistic work on that material.

What does all this mean for our view on fundamental objects in thermodynamics? Following mOSR, relations are the ways in which objects exist. Even if we do accept this position with respect to quantum mechanics and the relations of entanglement, this does not help us further with respect to thermodynamics. That is because those relations that are the ways in which thermodynamic objects exist are no longer only quantum mechanical relations.

The relations we are concerned with during the further development of the theory are different. They are relations of a second statistic's program. They are relations of the ensemble. Thus, we have to take a better look onto those ensemble-relations in order to find out whether they can be understood in the proper sense of mOSR.

To begin with, it is important to note that we are definitely talking about a highly relational framework. Second statistic is rightly understood to be a relational net with respect to the ensemble. Moreover, the statistical point of view very well confirms a structural position. Properties of (fundamental) objects shall exist in relations, instead of being intrinsic properties, and a statistic ensemble clearly confirms that idea.

Let us turn back to the situation of extensive and intensive properties to see why. I have already highlighted the crucial role of intensive properties. The definition of property T – the temperature – impressively demonstrates that role. The conception of an ensemble directly results in the fact that every single element is accessible with respect to a fixed macroscopic parameter consistent with preparation. Preparation creates an ensemble to the effect that all possible distributions cannot be distinguished from each other with respect to the fixed parameter. Each two of those representatives then, if brought into contact, show a very astonishing behavior. Some properties remain constant in subsystem A, in subsystem B, and in the connected system.

The reason for those intensive properties to remain constant is the fact that the probability to be in state A or B is the same. Both sub-systems A and B are still representatives of the ensemble which is defined by equal distribution of probabilities. If two of those systems are connected to each other, there is no reason to change into any other distribution. Given a weak thermal contact every change would lead into a less probable state. Every exchange of thermal energy thus will be compensated.

The situation thus describes a thermodynamic equilibrium. However, it is important to note that one does not start with stating an equilibrium. It is the idea and creation of an ensemble that leads to this situation. The equilibrium is created by establishing the ensemble. To presuppose equilibrium in order to use it as an advantageous condition to find thermodynamic properties would also mean to presuppose those properties the equilibrium refers to. The intention, however, is not to take those properties to be presupposed but to deduce them from a more general description. This makes a remarkable difference between statistical and phenomenological thermodynamics. The latter presets the equilibrium to be empirically observed. From the statistical perspective, using ensembles equilibrium thus is no presupposition, but an asset of the conception.

To put it in another way, it is a real and substantial discovery to find intensive properties in a connected system. The discovery is much less to be taken for granted than it is often suggested by talking about equilibrium states which are empirically observed. This is why most of the textbooks first deduce a factor β (out of equation 1) and afterwards define its reciprocal value 1/kβ *to be* temperature T. The theory has not found the kind of temperature we all seem to know empirically and phenomenologically (hot water or cold wind is something very different to temperature). The theory introduces and defines temperature.

Let us now assure ourselves why the property T is virtually ideal-typical a relational property. The ensemble as a whole represents the given thermodynamic system. The partition function (which is completely analogous to the $\partial ln\Omega$, see fn. 2) is defined over the whole net of ensemble-elements. Property β is linked to the average energy of a particle. Additionally, β is linked to another property T which is the absolute temperature of the system. T does not at all describe a sort of perception but a statistic feature of an aggregate of particles. Note that temperature T is defined for a system in statistical equilibrium and thus the well-prepared ensemble. T does not apply to a single particle or to a system which is not in equilibrium. T is a paradigmatic property of a relational net of a huge number of elements of an ensemble. T is neither a property of a single particle, nor of one single element of the ensemble. Thus, to take temperature to be an intrinsic property of any particle, sub-system, or system is simply wrong and utterly neglects the statistical point of view.

Given a physical system which is represented by an ensemble, the partition function, energy, average energy of a particle, but also volume or pressure – which are properties of the macroscopic state – are all functions of β and T respectively, and thus all inherit their relational character.

The question we are facing here is whether we can understand those relational properties in such a way that the relations are concrete, physical, and particular occurrences, and the ways in which thermodynamic objects exist. Do they meet the requirements of mOSR to understand "the properties of fundamental objects in relations"?

One should not make the mistake now to search for objects whose properties are described by the net of relations. In doing so one would pursue an idea which mOSR clearly rejects: an ontological priority either of objects or of relations. A conception like this requires an ontological difference between objects on the one hand, and properties including relations on the other hand. mOSR refuses such a difference (Esfeld and Lam 2011, 2012) and understands relations to be the ways in which objects exist.

Let us transfer this conception to statistical thermodynamics. The relations the theory uses are relations of the ensemble. To take the conception of ensembles just as a way to avoid the problem of missing knowledge about the exact states would mean not to get the idea of ensembles right. The conception is not a technical trick or an intellectual game in order to find a way from our lack of knowledge back to the original system via second statistics. On the contrary, the thermodynamic macroscopic properties as well as the central property of temperature and the partition function itself all are properties committed to the ensemble. The second statistic is closely related to the ensemble, and is emancipated from quantum mechanical statistics which only gives the number of possible states.

I have pointed out the fact that the group of relations – the ensemble-relations – should be regarded as a rather independent set of relations. This also gives us a strong argument at hand to defend the opinion of a non-reducible thermodynamic. If "relations of entanglement are the ways in which quantum objects exist" and if "metric relations are the ways in which space-time points exist", then ensemble-relations are the ways in which thermodynamic objects exist.

But now mOSR faces a severe problem, at least mOSR will be forced into a difficult concession. Without doubt the relations of entanglement in the case of quantum mechanics can be understood as concrete and particular relations. Likewise, the metric relations within space-time structures can be understood as concrete and particular relations. The occurrence of any such relation then can be understood to be concrete and particular just the same way as an occurrence of intrinsic properties.

However, it is not at all beyond all doubt to understand ensemble-relations as being that concrete and particular. Given a thermodynamic system whose temperature or pressure shall be determined, it seems quite inappropriate to speak of concrete relations of a (concrete) ensemble. That ensemble, which as a whole represents the system, is not present in any concrete manner. Consequently, the relations of the ensemble are not present in any concrete manner, too. Let me again point to the fact that the concrete relations of quantum particles do not sufficiently determine the ensemble-relations. Thus, we cannot, as in case of quantum mechanics or GTR attribute the same status of concreteness to the relational net of ensemble-relations.

To interpret the ensemble and its relations to be a concrete physical occurrence would bring some irritating problems of interpretation with it. The structural realist's interpretation of thermodynamic ontology then would face some problems rather similar – but much more occult – to the famous case of the so-called collapse of a wave function in quantum mechanics. In case of thermodynamics we had to speak of a concrete huge number of ensemble-parts including their relational net. In the very moment of calculation and measurement of a thermodynamic property, however, that concrete net had to spontaneously collapse towards the particular thermodynamic system.

In short, ensemble-relations are not concrete occurrences. Additionally, it is hard to see how those relations shall be understood as particular occurrences.

This does not mean that we are instantly forcing mOSr to step back and taking relations to be "defined on objects and their intrinsic properties". In case of a well understood theory of statistical thermodynamics the non-intrinsic view on properties is very well supported. It is so precisely by use of the conception of ensembles. Nevertheless, the very idea of what mOSR wants to take as a structure is seriously affected.

The development towards a moderate ontic structural realism was very much driven by changing the conception of structures compared with other forms of OSR. But now statistical thermodynamics seems to speak of relations which on the one hand very well satisfy some central ideas of mOSR, like non-intrinsic properties. On the other hand, however, the relational net itself consists of non-concrete and non-particular relations.

There seems to be no easy way out; still, it is a crucial claim of mOSR to take relations to be concrete and particular. By that very claim mOSR is characterized in opposition to different conceptions of OSR. If statistical thermodynamics is interpreted in a structural realist's sense – which is not at all unreasonable with respect to non-intrinsic properties – the structural realist is forced to accept what she was to refuse: the assumption of abstract structures. The relation revealed by analyzing statistical thermodynamics have to be assigned rather to a kind of possibility-space than to a concrete physical space. If those relations – being the ways in which objects exist – shall substantiate concrete occurrences of physical objects, they suspiciously look like abstract universals. And thus mOSR is forced to untangle a fact that it once tried to object against: the 'metaphysical' problem of an occult linkage between abstract relations and the sort of instantiation which shall exist between abstract relations and concrete particular physical occurrences and events.

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