Wesley C. Salmon versus G.W.F. Hegel on Causation, Principle of Common Cause and Theoretical Explanation

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Abstract: The aim of this article is to analyze the main contributions of Wesley C. Salmon to the philosophy of science, that is, his concepts of causation, common cause, and theoretical explanation, and to provide a critique of them. This critique will be based on a comparison of Salmon's concepts with categories developed by Hegel in his *Science of Logic* and which can be applied to issues treated by Salmon by means of the above given three concepts. It is the author's contention that by means of Hegelian categories it becomes possible to provide a critique of Salmon's philosophy of science and at the same time to enlarge the concept framework of philosophy of science.

Keywords: Salmon, Hegel, Reichenbach, causality, categories, theoretical explanation, common cause, causal loops

1 Introduction

The aim of this article is to analyze the main contributions of Wesley C. Salmon to the philosophy of science in the late 1970s and 1980s—that is, his concepts of *causation*, *common cause*, and *theoretical explanation*—and to provide a critique of them. This critique will be based on a comparison of Salmon's concepts with categories developed by Hegel in his *Science of Logic* (Hegel 1923; 1969),[1] and which can be applied to issues treated by Salmon by means of the above given three concepts. I realize that it is highly unusual, to say the least, to appeal to Hegel in the field of philosophy of science, but it is my contention that by means of categories it becomes possible to provide

[1] For a detailed analysis of Hegel's approach to causation covering all his works see Vetö (2000).

a critique of Salmon's philosophy of science and at the same time to enlarge the concept framework of the philosophy of science.

I start with the explication of what categories are. Then I analyze Salmon's approach to the category of causation. I show that instead of reconstructing *categories* that are subsidiary to the category of causation (that is, instead of conceiving the category of causation as a *cluster of categories*), he substitutes for those subsidiary categories *concepts of physics*. In addition, he reduces and in fact impoverishes the category of causation by taking into account only *unidirectional causal action* while leaving out *causal loops/closed causal chains*.

Next I show that the absence, on Salmon's part, of treating of epistemologico-ontological categories as the proper medium and tool for the philosophical analysis of science leads him to an incomplete reconstruction of Jean Perrin's computation of Avogadro's constant *N*. Finally, I show that the absence of treating epistemologico-ontological categories leads him to an incorrect understanding of what he labels "principle of common cause" and to a distorted understanding of what he labels "theoretical explanation."

2 What are Categories?

I view terms like "causality," "causal process," "phenomena," and so on, following Hegel,[2] as terms the meanings of which stand for the objective epistemic/cognitive content of human knowledge and where these meanings are the result of the cooperated thought-activity of human beings. At the same time these meanings serve as the basis for successive thought-activities generating a new objective and simultaneously intersubjectively valid epistemic/cognitive content.[3] In fact, the possession of these meanings enables the very process of human thinking to yield new objective content; they enable the

2 Here I draw on Walsh (1953/1954) and Hanzel – Černík – Viceník (1994).

3 By claiming that categories have not only an epistemological but also an ontological dimension, i.e., objective content, I follow Hegel's and not Kant's approach to categories. For differences between Kant's and Hegel's approaches to categories see Horstmann (1995). I view at the same time the objective and intersubjective dimensions of categories as not reducible to each other. Of course, that a category says something about the real world is a contention that has to be tested.

growth of knowledge. And because these meanings stand for an *objective* content, they can be viewed as characterizing human knowledge/ cognition of real objects. They can, therefore, reproduce—by means of thought-operations—a really existing object as an object in thought, that is, as a thought-object. What has to be emphasized here is that the meanings of terms like "causality," "causal process," phenomena," and so on, are different from the meanings of terms like "gene," "molecule of oxygen," or "wave function" because their reference is not immediately an object in the external world, but a general type of thought-object that is an invariant for different thought-objects given in the natural and social sciences.

At the same time, the meanings of those terms can be viewed, at least in human society in which science is given, as the determinants and coordinators of scientific research, the framework determining the creation of scientific theories. The meanings of those terms express what is common to several natural and social sciences of a certain historical period, what unifies them and what is general and necessary for them. Without these meanings it is impossible to think any object; human beings need them for the creation of thought-objects given in natural and social sciences and expressed in their own specific terms. According to Kant, by means of categories we can not only "think an object" (§ 10, A80/B106; Kant 1964, 114) but also "[w]e cannot think an object save through categories" (§ 27, B165; Kant 1964, 173).

I label those meanings *epistemico-ontological categories of thinking* or *categories*, for short, and regard them as enabling both the epistemic/cognitive relation of human beings to the objects of their cognition and the development of this relation. They should thus be understood as thought-expressions or abstractions of the real determinations. Even if they are higher-level thought-expressions or abstractions of meanings for the terms of the natural and social sciences, still they stand for knowledge about the external reality. They are however *not* thought-expressions of the real determinations of external reality by itself (these are given by the meaning of the terms of the natural and social sciences), nor of the thinking by itself, but are the abstractions of the determinations of real relations between thinking, nature and society. *The givenness of these relations is the essential condition for the existence of categories of thinking; they are given only where the relation between being and cognition, subject and object exists.*

And since I am dealing in this article only with scientific *theories*, I can understand categories as *thought-expressions of the relations really given between the cognizing thinking of human beings and the cognized reality, as the modes of the reproduction and reconstruction of the objective in the subjective consciousness of human beings, as modes of their thought-appropriation of the reality that is external to thinking*. This means that *I depart from Hegel's idealistic approach that views nature, society, science with its concepts, etc. as the emanations of logico-metaphysical categories*. Accordingly, since I view the latter as standing for degrees of the development of scientific knowledge, I can employ them in the analysis of scientific theories.

3 Salmon vs. Hegel on causation

As the basic subsidiary concepts of the category of causality, Salmon takes those of *process* (vs. pseudo-process), *mark*, and *mark-transmission* (Salmon 1984, 139–155). Processes are, according to him, entities that, when compared to events, "have much greater temporal duration, and in many cases, much greater spatial extent" (Salmon 1984, 139). The meaning of the term "process" is then specified by him by drawing on the *special theory of relativity from physics*. Based on this theory Salmon states the following:

> causal relations must be accorded a fundamental place in the special theory of relativity… any given event E_0, occurring at a particular space-time point P_0, has an associated double-sheeted light cone. All events that could have a causal influence upon E_0 are located in the interior or on the surface of the past light cone, and all events upon which E_0 could have any causal influence are located in the interior or on the surface of the future light cone. All such events are *causally connectable* with E_0. Those events that lie on the surface of either sheet of the light cone are said to have a *lightlike separation* from E_0, those that lie within either part of the cone are said to have a *timelike separation* from E_0, and those that are outside of the cone are said to have a *spacelike separation* from E_0. The Minkowski light cone can, with complete propriety, be called "the cone of causal relevance."… Special relativity demands that we make a distinction between *causal processes* and *pseudo-processes*. It is a fundamental principle of that theory that light is a *fist signal*—that is, no signal can be transmitted at a velocity greater than the velocity of light in a vacuum. There are, however, certain processes that can transpire at arbitrary high velocities—at velocities

> vastly exceeding that of light. This fact does not violate the basic relativistic principles, however, for these 'processes' are incapable of serving as signals or of transmitting signals: Causal processes are those that are capable of transmitting signals; pseudo-processes are incapable of doing so. (Salmon 1984, 141)

As an example he mentions the case when in a very large circular building—a kind of a super-Astrodome—a rotating spot-light is placed at its center. The pulses of light traveling from that spotlight to the walls of the building represent, according to Salmon, a causal process while the spotlight traveling on the wall of the building represents a pseudo-process; the former, but not the latter, can transmit a mark. So, for example, when one places a red filter in front of the rotating spotlight, the change of color is moved from the source of the light up to the wall. But if one places a red filter right in front of the wall, the light is turned red in that location but not in other locations where the spot moves. Based on this analysis, Salmon draws the conclusion that a "causal process is one that transmits energy, as well as information and causal influence" (Salmon 1984, 146).

Salmon's approach to causality is, on the one hand, based on a *specific physical theory*, and the *concepts falling under the category of causality are either taken directly from that theory or, at most, modeled on those concepts*. But, on the other hand, Salmon's endeavor to deal with the category of causality and its subsidiary concepts aims at something more general and at the same time more rich, namely, to provide *a set of categories falling under the category of causality that would cover also cases different from those described in the special theory of relativity*. So, for example, he claims that

> our main concern with causal processes is their role in the propagation of causal influence; radio broadcasting presents a clear example. The transmitting station sends a carrier wave that has a certain structure—characterized by amplitude and frequency, among other things—and modifications of this wave, in the form of modulations of amplitude (AM) or frequency (FM), are imposed for the purpose of broadcasting… Such processes are the means by which causal influence is propagated in our world. Causal influence, transmitted by radio, may set your foot to tapping, or induce someone to purchase a different brand of soap. (Salmon 1984, 146)

This means that the (categorial) structure of the category of causality *based on the concepts of just one physical* theory, namely, the special theory *of relativity*, is extended by Salmon not only to the *whole* of physics (with the exemption of quantum mechanics) but also to *human action*. The truth is however that in order to induce a person to tap his/her foot, it is causally irrelevant if the sound waves from the radio move with a high or low velocity or that the speed of that tapping cannot exceed the speed of light. And in the same manner, the speed of the radio waves by which advertisements are broadcasted is causally irrelevant for a person's switch from, say, Karcher soap to Lever 2000 soap. Salmon's understanding of the category of causality does not fulfill one of the central requirement put on categories by Kant, namely, that they stand for an *object in general* (§ 14, B128; Kant 1964, 128), and that this generality should unify in itself the *richness of particular cases/objects*.

Let us now compare Salmon's approach to causality with that of Hegel (Hegel 1923; 1969).[4] Hegel, in order to access the category of causality in its completeness, uses as the point of departure the category of *substance* understood, first, as a process, structure, etc., *not being acted upon nor as acting on something else*, and thus as inherently passive (Hegel 1923, 186; 1969, 556).

Next, he approaches substance as already endowed with (creative and destructive) *powers* via which it can enter into relations with its accidents, where these relations are the bases for the relation of causality (Hegel 1923, 187; 1969, 556–557).

Then, he distinguishes three category clusters pertaining to the relation of causality. At the level of *formal causality*, the power of the substance, that is, what it is in itself (das *An-sich*) is manifested by means of its accidents as an effect, while at the same time the actual substance stands outside the generation of the effect; it is still the original (*das Ursprüngliche*) and, thus, as yet not posited (*gesetzt*), that is, *not explained* (Hegel 1923, 189–190; 1969, 558–559). From this Hegel draws the conclusion that "the actuality which the substance has as a cause, it has *only in its effect*" (Hegel 1923, 190; 1969, 559). It holds, according to him, also that the *effect* is "*necessary* because it is just the

4 For a more concise treatment of the category of causality see §§ 150–159 in Hegel (1975).

manifestation of the cause or this necessity which is the cause… [it is an] *independent source of production out of itself*; it must *act*" (Hegel 1923, 190; 1969, 559).

Hegel, therefore, also states that once we take the relation of a certain cause to its specific effect, thus, leaving out determinations that are irrelevant for this cause in respect to this specific effect, then "*effect contains… nothing whatever that cause does not contain*. *Conversely, the cause contains nothing that is not in its effect*" (Hegel 1923, 190–191; 1969, 559).

At the level of the category cluster of *the determinate causal relation*, Hegel reflects on the relation of cause and effect with respect to the category of substance in such a way that the effect is produced in a substance that is different from that to which its producing cause is related; to the former substance he therefore assigns the category of *substrate* (Hegel 1923, 197; 1969, 565). In fact, according to Hegel, one has here an *active* substance related to the cause and a *passive* substance related to its effect. What holds here also for such a type of causality is that the produced effect turns into a cause producing yet another effect; one obtains here a causal chain going into infinity which Hegel qualifies as the "bad infinite" (*das Schlecht-Unendliche*) (Hegel 1923, 197; 1969, 565) because here the *cause* (even if it is an effect) produces an effect and this its *effect* (even if it a cause) *differs from its cause*.

The overcoming of the bad infinite determination of causal chains is accomplished according to Hegel in the categories of *action* and *counteraction* (*Wirkung und Gegenwirkung*). Here causality is understood already as a *presupposing acting* (*voraussetzendes Tun*) (Hegel 1923, 198; 1969, 566), so that the cause itself is *conditioned* by the effect and, according to Hegel, one has here, not a passive substance and an active substance in which causality should reside, but only one substance, while the reaction *redirects the cause against the first/initial acting cause*. From this it follows that at the level of the category of *conditioned causality* "the cause *relates* in the effect to *itself*" (Hegel 1923, 202; 1969, 569). By means of this, Hegel passes, as a conclusion of his categorial reflections on causality, to the category cluster of *mutual action* (*Wechselwirkung*), where

> [t]hat first cause, which first acts and receives the effect into itself as counteraction, thus reappears as cause, whereby… action going into badly infinite progress is *bent around* and becomes an into itself returning… *mutual action* (Hegel 1923, 202; 1969, 569).

Simultaneously, substance, initially understood as passive is now understood as *active* and *self-related*. In order to grasp at the level of categories this activity and self-relatedness, he brings in the category of *subject* understood as the *source of self-activity*; simultaneously Hegel unifies the category of substance with the category of subject into that of *substance-subject*.

This means that Hegel in his reflections on causality *bypasses the use of any concepts other than categories; he thus moves exclusively within the framework of category clusters*. So, from the meta-philosophical point of view, one can criticize Salmon's philosophical approach to causation for not holding strictly to a language of categories.

Worth noting is that by differentiating between the clusters of formal causality and of mutual action, it is possible to approach Salmon's characterization of the category of causality from yet another point of view.

Salmon claims that in his approach to the concept of causation, he draws on the views of Hans Reichenbach and states that

> [i]n his posthumous book, *The Direction of Time* (1956), [Reichenbach] enunciated the principle of the common cause, and he attempted to explicate the principle in terms of a statistical structure that he called a *conjunctive fork*. The principle of the common cause states, roughly, that when apparent coincidences occur that are too improbable to be attributed to chance, they can be explained by reference to a common causal antecedent. Reichenbach claimed… that conjunctive forks possess an important asymmetry. Just as we can have two effects that arise out of a given common cause, so also may we find a common effect resulting from two distinct causes… Reichenbach distinguished three situations: (1) a common cause *C* giving rise to two separate effects, *A* and *B*, without any common effect arising from *A* and *B* conjointly; (2) two events *A* and *B* that, in the absence of a common cause *C*, jointly produce a common effect *E*; (3) a combination of (1) and (2) in which the events *A* and *B* have both a common cause *C* and a common effect *E*. (Salmon 1984, 158, 163)

These three possible situations can be represented as shown in Figure 1.

A more detailed look at the works of Reichenbach reveals, however, that Salmon has provided a *highly selective* and in fact a *reductive* reading of Reichenbach's approach to the category of causality, that is, he did not take into account in his own typology of possible causal relations the fact that Reichenbach *reflected on the possibility of causal loops/closed causal chains and that he endorsed the possibility of the latter*.

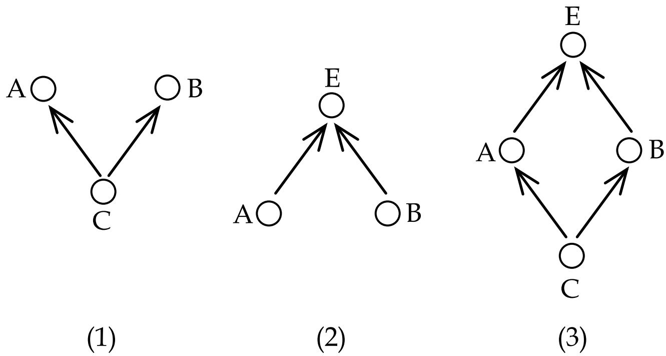


Figure 1. Salmon's conjunctive forks

Reichenbach in his *Direction of Time* states that "[t]raveling along causal chains we… make the discovery that we never return to the starting point; or; to put it another way, that there are no closed causal chains" (Reichenbach 1956, 36). He represents a closed causal chain by the scheme shown in Figure 2 and accompanies it with the comment that "arrangements of this kind never occur" (Reichenbach 1956, 39).

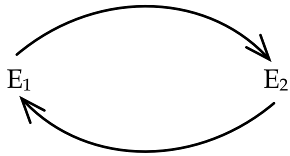


Figure 2. H. Reichenbach on closed causal chains/causal loops

In his *Philosophy of Space and Time* he then clarifies what he means by arrangements "never occur." He suggests, as an example, the mechanism of an electric bell, which seemingly functions on the basis of a closed causal chain/causal loop represented in Figure 3.

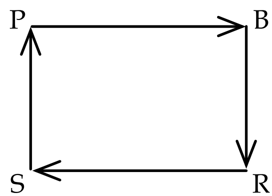
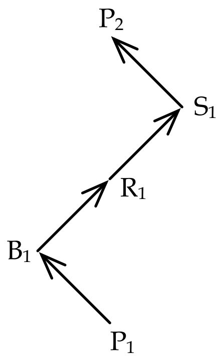


Figure 3. H. Reichenbach on the functioning of an electric bell

Reichenbach states:

> The pulling (P) of the lever causes a break (B) in the current, which in turn causes a return (R) of the lever; this switches on (S) the current which finally pulls the lever. It appears as though this chain could be diagrammed [by]… a close curve. The mistake in this argument, however, is easily seen. The individual pulls of the lever are different events, i.e., although they are of the same kind, they are not identical events. Consequently, the chain should be diagrammed as… an open chain.



> Our principle of the mark forces us to this conception. If we make some change in B_1 by short-circuiting the current and thus preventing the return of the lever, then P_2 will no longer occur. However such inference does not change P_1. (Reichenbach 1958, 139–140)

Based on this argument, Reichenbach affirms the possibility of causal loops/closed causal chains. *They return to the same kind of events, not the same singular events*; "[n]ow it is clear what we mean by a closed chain, namely a chain that returns *to identically the same event*, not to one of the same kind" (Reichenbach 1958, 140). Thus, Reichenbach's view on causal loops is related not to individual tokens of events but to a kind of events. And the implication for Salmon's approach is that even if Salmon deals with particular cases involving to individual tokens of events, his approach can be generalized[5] to a kind of events. Then comes to the surface the reductive nature of Salmon's approach to causation.

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[5] On this generalization see, e.g., Hanzel (1999).

I thus arrive at the conclusion that Salmon has not only failed to reconstruct *categories* that fall under the category of causality, but also, *by excluding reflections on cyclical causal processes*, has from the very beginning severely restricted the possibility of constructing a rich *cluster of categories for the category of causality*. One can thus also reproach Salmon at the level of his very *philosophy* because he has impoverished the categorial cluster in it which he deals with the issue of causality.

Hegel, unlike Salmon, by distinguishing between the categorial clusters of formal causality, action and counteraction, and mutual action, has provided an *inherently rich and differentiated network of categories* falling under the category of causality where one can already make reflections on closed causal chains/causal loops.

The importance of such a rich and differentiated network of categories for the philosophy of science is given by the fact that it provides the framework for a philosophical analysis of scientific theories that explicitly employ the category of closed causal chains/causal loops. An interesting case of such a theory is Manfred Eigen's attempt to explain the origin of life on Earth. Already in the introduction of his first paper dealing with this issue, Eigen under the caption "cause and effect" starts with the following claim:[6]

> The question of the origin of life very often appears as a question about 'cause and effect'… It is mainly due to the nature of this question that many scientists believe that our present physics does not offer any obvious explanation for the existence of life… As a consequence of the exciting discoveries of 'molecular biology,' a common version of the above question is: *What came first, the protein or the nucleic acid?* The term 'first' is usually meant to define a causal rather than a temporal relationship, and the words 'protein' and 'nucleic acid' may be substituted by 'function' and 'information.' The question in this form, when applied to the interplay of nucleic acids and proteins as presently encountered in the living cell, leads ad absurdum because 'function' cannot occur in any organized manner unless 'information' is present and this 'information' only acquires its meaning *via* the 'function' for which it is coding. Such system may be compared to a closed causal loop… The present interplay of nucleic acids and proteins corresponds to a complex hierarchy of 'closed loops.' (Eigen 1971, 465–67)

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6 Here we hold to Eigen's initial view, namely, that the mutual relation of hypercycles is a causal type of relation.

Eigen models such a hierarchy by means of various types of hypercycle; its realistic model is represented as shown in Figure 4 (Eigen and Schuster 1979, 5).

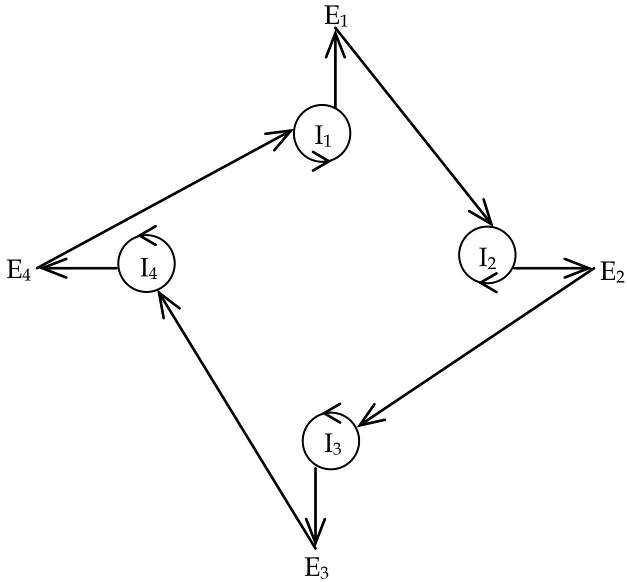

Figure 4. M. Eigen's realistic model of hypercycle

Here I_i stands for an information carrier exhibiting two kinds of instruction: one for its own reproduction and the other for the translation into an intermediate (enzyme) E_i, which in turn provides catalytic help for the reproduction of the subsequent information carrier I_{i+1}. The realistic model of a hypercycle conforms to the first principle of evolution which Eigen formulates as follows: *The individuals among which selection is to take place must be self-reproducing entities; they are replicators* (Eigen 1976; Eigen – Schuster 1979; Eigen – Schuster 1982; Eigen – Winkler-Oswatitsch 1992).

Worth mentioning, with respect to this paper, is Eigen's second principle of evolution. *Self-reproduction is subject to errors. This means that some replicators come into existence, not as a result of true copying of an identical parent, but as consequence of inaccurate copying of one that is closely related* (Eigen 1976; Eigen – Schuster 1979; Eigen – Schuster 1982; Eigen – Winkler-Oswatitsch 1992). The importance of this principle, with respect to the framework of the category cluster of mutual action and in respect to the category of substance-subject, is that it enables one to go beyond Salmon's as well as Reichenbach's understanding of how a causal process can be marked. While Reichenbach in his bell-example and Salmon in his super-Astrodome example suppose that a causal process is marked from the *outside*, by an intersection with another, different causal process, Eigen's second principle of evolution suggests that in a cyclical type of causal processes, the kinds of constituents of these causal processes can change by themselves; thus causal processes of this type *mark themselves*. Understood in this way, causal processes then correspond to what the category of substance-subject in fact enables: the provision of a thought-representation of a causal process as an *activ*e, *self-related* and *self-developing process*.

4 Salmon on Molecular Reality: A Critique from the Point of View of Hegel's "Retreat into the Ground and the Emergence from it"

Let us now return to Salmon's common-cause principle. Worth mentioning is how Salmon initially introduces this principle. He gives the following example:

> Suppose… that several members of a traveling theatrical company who have spent a pleasant day in the country together become violently ill that evening. We infer that it was probably due to a common meal of which they all partook. When we find that their lunch included some poisonous mushrooms that they had gathered and cooked, we have the explanation. (Salmon 1984, 158)

This means that he uses common-sense terms and does not reconstruct epistemico-ontological categories in order to describe the process of, first, how a common cause (e.g., the presence of spoiled food in a hotel restaurant) is *inferred/discovered* based on the prior discovery of the effects of that cause (the discovery that the actors were poisoned by spoiled food) and, second, how these effects are, then, *explanatory-derived* from their common cause. Salmon thus initially introduces the common-cause principle in the framework of *epistemology*, while at the same time he *bypasses here any categorial analysis*. Then, however, he suddenly leaves the framework of epistemology and, by considering the three types of conjunctive forks (see Figure 1), shifts to reflections about the common-cause principle that are located completely inside the framework of *ontology*. The fact that Salmon shifts from epistemology to ontology and in the former does not embark on the reconstruction of categories leads, at least in my view, to a distorted reconstruction of the process of how science relates phenomenological quantities to the quantities underlying them; the former are labeled by Salmon as "macroquantities" and the latter, "microquantities." As an example for his reconstruction, he has chosen Jean Perrin's experiments enabling the computation of Avogadro's constant *N*. Perrin described these experiments and performed these computations in his articles published in 1908 (Perrin 1908a; 1908b; 1908c). In order to locate the shortcomings of Salmon's approach let us give, first, an overview of Perrin's experiments and computations.[7]

Jean Perrin's experiments and computations are initially framed by him as follows:

> (1) Any particle placed into a liquid in equilibrium moves in a continuous and perfectly irregular manner, so that the smaller it is, the more vivid this motion is (Brownian motion).
> (2) This eternal motion is an essential property of liquids.
> (3) It is an already visible consequence of molecular collisions, produced in an irregular manner, with the particle. (Perrin 1908a, 967–68)

Based on these statements, he prepared an emulsion of natural latex, and after subjecting it to a sequence of treatments he took one droplet of it as a microscopic preparation the thickness of which was approximately 0.12 mm. This enabled him to investigate the distribution of the granules according to the height of the preparation. By taking the average of distributions from several thousands of tests, he found out that if he represented the concentration of the granules by the numeral 100 for a certain level, then for the levels that where 25, 50, 75 and 100 microns below that certain level, the concentration was given by the numerals 116, 146, 170, and 200 or 119, 142, 169, and 201, which differed from the previous only due to observation-errors. So as the second series of numerals stands for a geometric progression, Perrin draws the conclusion that

7 Here I hold to the system of units used by Perrin.

> [t]he distribution of the equilibrium in the preparation (and probably in any colloidal solution) is thus exponential like for a gas in equilibrium under the impact of weight. Only the decrease by half of the concentration produced in the atmosphere at the height of 6 km, is produced here for a height of 1/10 of a millimeter. (Perrin 1908a, 968–969)

In the next step Perrin proposes the following mathematical treatment of the distribution of the granules in the colloid. He considers identical granules with density ρ and mass m, the concentration of which is n in a unit of volume, and that by their impacts on the wall that stops them produce an osmotic pressure proportional to their concentration, this pressure being kn. So, ndh granules given in a horizontal layer of a thickness dh and a unit cross-section are maintained in suspension by the sum of the Archimedean pressure and the difference of the osmotic pressures on the two surfaces of the layer. This leads him to the differential equation:

$$\frac{dn}{n} = \frac{1}{k}\, g\, dh\, (1 - \frac{1}{\rho})\, m$$

Its integration in the boundaries from 0 to h yields:

$$2.3 \log_{10} \frac{n_0}{n} = \frac{1}{k}\, m\, g\, h\, (1 - \frac{1}{\rho})$$

Based on this equation, Perrin computes, first, the value of the constant k based on the knowledge of m and ρ. In order to compute the value of the mass m of the granule he applied Stokes's law[8] to an experiment in which a vertical column several centimeters high of an emulsion with the granules was placed into a capillary tube. The granules from the upper layers fall like droplets from a cloud, according to Perrin's experiments, at a rate of 0.97 mm per day. By the application of Stokes's law, relating the velocity of the spherical droplet with its radius and the viscosity of the medium, he computed that m equals 9.86×10^{-15}, which in turn yielded a k equal to 360×10^{-16} and, thus, the osmotic pressure p equaled to $n \times 360 \times 10^{-16}$. Finally, Perrin drew on the kinetic theory of gases, according to which "this pressure is equal to that which would be produced in the same volume by the

8 On this see Perrin (1908b).

same number of molecules of any ideal gas, that is, equal to $n\frac{RT}{N}$," (Perrin 1908c, 531), where R stands for the universal gas constant, T for absolute temperature, and N for the number of molecules in one gram-mole. Based on the relation between p, on the one hand, and N, R, and T, on the other, Perrin computes N as equal to 6.7×10^{23}.

Salmon, when dealing with Perrin's experiments and computations makes the following three claims that (i) the number N "is *the* link between the microcosm and the macrocosm" (Salmon 1984, 214); (ii) "the mass of the Brownian particle and the average velocities of the molecules are quite directly measurable" (Salmon 1990, 125); and (iii) with respect to the application of the kinetic theory, Perrin's computation of N was based on the fact that: "[d]uring the nineteenth century, the ideal gas law $PV = nRT$ was derived from the kinetic theory of gases" (Salmon 1984, 218).

However, if one takes a closer look at Perrin's computations, one finds out that their basis and framework include the following crucial presuppositions:

1. The Brownian movement of the particles of the colloids is a visible consequence of the collisions of the particles of the liquid, by themselves unobservable, with the particles of the colloid.
2. There exists an analogy between the behavior of gas molecules and the behavior of the particles of the colloid; therefore the kinetic theory of gases can be applied to the Brownian movement.
3. One can apply Stokes's law to the movement of the particles of the colloid.

This thus means, *first*, that there is no way to directly compute the microquantity of the mass of a Brownian particle. In order to compute it, one has to apply Stokes's law; it is thus a microquantity, which can be *measured only indirectly*. *Second*, the relations of phenomenological thermodynamics are not derivable in the full sense of "derivable" from the kinetic theory of gases. In order to derive them from kinetic theory relations, initially given in the framework of phenomenological thermodynamics, one needs *in advance* the latter and then one can unify them with the kinetic theory. As an example let us take the equation $p = n\frac{R}{N}T$ used by Perrin in the computation of N.

Let m_i and v_i stand for the mass and velocity, respectively, of a molecule in an ideal gas with n as the total number of molecules. For the total energy of such a gas it holds that $\sum_{i=1}^{n} \frac{1}{2} m_i v_i^2$ = const. Let us now introduce the mean square speed, which is the speed all molecules of an ideal gas should have in order for its total energy to be equal to its real energy. Let us suppose that all molecules have the same mass m, and that n_1 molecules move with the speed of v_1, n_2 molecules move with the speed of v_2, and so forth, so that $\sum_{i=1}^{l} n_i = n$. The total energy of all molecules then is $\frac{1}{2} n_1 m v_1^2 + \frac{1}{2} n_2 m v_2^2 + \ldots = \frac{1}{2} m \sum_{i=1}^{l} n_i v_i^2$. If all n molecules would have the same speed C, then the energy of the gas would be $\frac{1}{2} nmC^2$, and C would be determined by the following condition $\frac{1}{2} m \sum_{i=1}^{l} n_i v_i^2 = \frac{1}{2} nmC^2$. Thus we have obtained for C^2 as the mean square speed $C^2 = \frac{1}{n} \sum_{i=1}^{l} n_i v_i^2$. The values for C^2 can be found out by considering an ideal gas with N_0 molecules closed in a spherical container with a radius of r. It can be proved that a molecule with mass m acts on the wall of the container with a mean force equal to mC^2/r. From the total number N_0 of molecules a unit area is hit by $N_0/4\pi r^2$ molecules whose resultant force acting on the unit area is equal to the effect of the pressure acting on the wall; for this pressure it holds that $p = \frac{N_0 m C^2}{4\pi r^3}$ as well as $p = \frac{M_0 C^2}{4\pi r^3}$, where $M_0 = N_0 m$ stands for the total mass of the gas. If we multiply these equations with the volume v_m of one kilo-mole of the ideal gas, that is, $v_m = \frac{4}{3} \pi r^3$ kmol^{-1}, we obtain the relations

(1) $$p v_m = \frac{1}{3} NmC^2$$

(2) $pv_m = \frac{1}{3}MC^2$

where N is Avogadro's constant. If we now compare (1) with the equation of state $pv_m = RT$ from phenomenological thermodynamics, we obtain

(3) $\frac{1}{3}NmC^2 = RT$

By multiplying both sides of the equation (3) by $\frac{3}{2N}$, we have

(4) $u = \frac{1}{2}mC^2 = \frac{3}{2}\frac{R}{N}T$

The last equation states that u, the *mean energy of a molecule of a gas (composed of identical atoms) is proportional to the absolute temperature*.

By dividing both sides of (1) by v_m, we have

(5) $p = \frac{1}{3}nmC^2$,

where n stands for the number of molecules in a unit of volume. Finally, by substituting (4) into (5) we obtain the equations

(6) $p = \frac{2}{3}nu$

(7) $p = n\frac{R}{N}T$

From this I draw the conclusion that the derivation of equation (7) is based on (a) the employment of mechanics to gases and fluids (via the concept of pressure understood as force F exerted per unit area S; $p = \frac{F}{S}$); (b) the employment of the concept of force from mechanics inside kinetic theory; and (c) the employment of the equation of state from phenomenological thermodynamics inside the kinetic theory. In the derivation of equation (7), we thus have the sequence of employed theories represented in Figure 5.

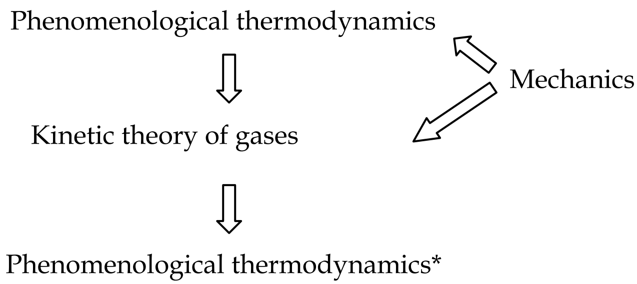

Figure 5. Sequence of theories employed in the derivation of $p = n\frac{R}{N}T$

The star appearing next to the term "Phenomenological thermodynamics" stands for the difference between the concepts belonging initially to phenomenological thermodynamics and concepts now obtained from kinetic theory; for example, the concept of pressure, initially introduced in phenomenological thermodynamics as $p = \frac{F}{S}$, now becomes $p = n\frac{R}{N}T$.

It is worth noting that Hegel provides a cluster of categories that fits the sequence represented in Figure 5. He introduces the category of *ground*, which he characterizes as the structure underlying the respective phenomena under investigation and, at the same time, distinguishes at the level of categories between the *phenomena that are at the beginning of the sequence* represented in Figure 5 and the *phenomena that are at the end of this sequence*. To the former he assigns the category *appearance*, while to the latter the category *manifestation*. The *epistemic* difference between them is given by the fact that *manifestations* are part of the meaning of the expressions in which the expressions that refer to their ground are *always* embedded. *Appearances*, contrary to this, are free from any epistemic/cognitive connections with the knowledge about the underlying ground. Thus, while pressure as a concept at the level of appearances is understood as $p = \frac{F}{S}$, at the level of manifestations, as is readily seen in equations (6) and (7), it is related to the concept of mean energy as well as to N and n, which as microquantities characterize the ground of thermodynamic macro-phenomena.

From the point of view of Hegel's categories one can bring in an additional characterization of equations (4) and (6) which departs from their standard interpretation in contemporary philosophy of science. According to the standard interpretation, the equations relating macroquantities and microquantities are viewed as *identities*. Based on Hegel's categories given above, I interpret these equations in a different way, namely, as standing for what can be labeled as "expressive relations." They relate a *specific ground that has its own existence* to its phenomena where the latter are produced by the former. Accordingly, one would not be justified in interpreting, for example, the relation of the mean energy of micro-particles of a gas to its macro-property of temperature as the relation of identity because it is possible to imagine a situation (a "possible world") where there exist microparticles endowed with microproperties, but whose concentration is so low that they do not create the macro-entity gas endowed with macro-properties like temperature.

At the same time, Hegel in a *strictly categorial language* expresses the epistemic/cognitive movement from appearances via ground to manifestations as the "retreat into the ground and the emergence from it" (1923, 83; 1969, 462). Worth noting also is that Hegel not only provides a categorial reconstruction of the movement appearance→ ground → manifestation, but differentiates between two categories of ground. Based on this differentiation one can evaluate Salmon's views on the principle of common cause and on theoretical explanation.

5 Salmon on the Principle of Common-Cause and Theoretical Explanation versus Hegel on Formal and Real Ground

Let me return to equations (4) and (6). They display a highly specific epistemic/cognitive feature, namely, that they unify macroquantities and microquantities in a specific way. The equation $u = \frac{3}{2}\frac{R}{N}T$ relates the macroscopic feature of the absolute temperature of a gas with the kinetic energy of the chaotic movement of its microparticles in such a way that *by measuring the former one can compute the latter*.

The same holds also for $p = \frac{2}{3} nu$: by measuring *p*, and by simultaneously employing the results of computing *u*, based on $u = \frac{3}{2} \frac{R}{N} T$, one can compute *n*. Thus the measurement of macroquantities *T* and *p* enables one to compute the microquantities *u* and *n*, which *cannot be measured directly* in the framework of kinetic theory. This fact was expressed by Hegel by introducing the category of *formal ground*, which stands for a *level of knowledge about the ground of phenomena as appearances, when we are as yet not able to quantify/measure the ground independently of the quantification/measurement of the phenomena as appearances*.

And again, as before, Hegel assigns a whole cluster of categories falling under a category; with respect to formal ground they are *ground* and *grounded* (*Begründetes*), relation of the ground (*Grundbeziehung*), posited (*Gesetzte*) and basis (*Grundlage*). According to Hegel, the description of the phenomena as appearances "is the identical basis of the ground and grounded" (Hegel 1923, 79; 1969, 459); thus for the formal ground it holds "that it has no other content than the phenomenon itself" (Hegel 1923, 79; 1969, 459). The reasonable requirement that "the ground should have *another content* than that what should be explained" (Hegel 1923, 80; 1969, 459) is not fulfilled at the level of knowledge characterized by the category of formal ground, because

> in this way of explanation the two *opposite directions* of the relation of the ground are given without being recognized in their determinate relation. The ground is, on the one hand, ground ... of the phenomenon which it grounds; on the other hand, it is the posited. It is that from which the phenomenon is to be understood; but *conversely*, it is from the latter from whom the ground is inferred and understood… the ground, instead… of being independent, is therefore rather the posited and derived. (Hegel 1923, 80; 1969, 459)

At the level of knowledge characterized by the category of formal ground "one finds oneself in a kind of a vicious circle in which… ground and grounded… are mixed up in an indiscriminate company and enjoy equal rank with one another" (Hegel 1923, 82; 1969, 461), and in order to escape this vicious circle in knowledge one should move from the category of formal to that of *real ground*; here the ground is posited by knowledge that is already independent of the knowledge of phenomena as appearances (Hegel 1923, 83; 1969, 462).

If we now compare Hegel's categorial distinction between formal and real ground with what Salmon labels as "theoretical explanation," it becomes readily apparent that Salmon provides a rather incomplete understanding of theoretical explanation. While he views Perrin's computation of *N* as a case of *theoretical explanation* (Salmon 1984, 214), via Hegel's categories of formal and real ground it becomes evident that it is a case of indirect measurement that in a *noneliminable manner depends on empirical (phenomenological) knowledge*. Therefore, the movement of knowledge *from* the phenomenological characteristics of gases as well as their measurement *to* the computation of Avogadro's constant *N* exemplifies the movement from the phenomena as appearances to the formal ground. Thus *it does not stand for theoretical knowledge in the proper sense of this term but for as yet only empirico-theoretical knowledge. Only knowledge in the framework of the category of real ground can be viewed as genuine theoretical knowledge*.

For what would the knowledge at the level of real ground stand for in the case of the computation of Avogadro's constant *N*? Salmon, drawing on Perrin, shows that this constant can be computed by the following five ways: by the phenomenon of Brownian motion, as shown earlier; as well as by the phenomenon of alpha decay, X-ray diffraction, black-body radiation, and electrolysis (Salmon 1984, 217–19). Once *N* is computed on the basis of these phenomena, the next step should be to find out *why N* has the value it actually has. Thus, the aim in the long run should be to compute *N* by using only microquantities while completely bypassing the usage of macroquantities in this computation.

With this in mind it becomes readily apparent that Salmon has misunderstood that which he labels as *principle of common cause*. He states, with respect to Perrin, that

> [t]he claim I should like to make about the argument…, stated… by Perrin, is that it relies upon the principle of common cause—indeed that it appeals to a conjunctive fork (Salmon 1984, 220),

while at a more general level he states:

> There is a familiar pattern of causal reasoning that we all use every day… Confronted with what appears to be an improbable coincidence, we seek a common cause. If the common cause can be found, it is invoked to explain the coincidence. (Salmon 1984, 158)

From my analysis, based on the categories of ground, formal ground, and real ground, based on Perrin's computation of *N*, I draw the conclusion that Salmon *has not differentiated between the phase of cognition where one moves from phenomena as appearances to their ground and the phase where one moves, once that phase has been accomplished, from the ground to its (phenomena as) manifestations*. Perrin's computation of *N* corresponds to the former movement. However, only the *whole* cyclical movement from phenomena as appearances to phenomena as manifestations corresponds to what Salmon labels *common cause principle* and *conjunctive fork*. Nor has Salmon considered the possible situation, exemplified by Perrin's computation of *N*, that the *movement, after the movement from appearances to the ground has already been accomplished, has to stop at the level of ground without going back to the phenomena as manifestations, because the ground has been grasped as yet only as a formal ground*. The latter cannot serve as a sufficient explanatory basis for the movement from the ground to its manifestations. I, therefore, restate Salmon's claim, quoted earlier, that "[i]f the common cause can be found, it is invoked to explain the coincidence" as follows: *If the common cause is found, first, as a formal ground and, then, as a real ground, it can be invoked to explain the coincidence.*

6 Conclusion

From the above analysis I draw the following conclusions. First, the endeavor to deal explicitly with epistemico-ontological categories, which—in respect to science—*belong to a metascientific* level, is a necessary instrument for a philosophical analysis of science and for leading the philosophy of science to new results. Second, I view the reconstruction of epistemico-ontological categories as enabling a more detailed and precise understanding of the functioning of science. Third, this prominence of categories and their absence in the works of Salmon led him to a reduced and incomplete understanding of causality, of the principle of common cause and of theoretical explanation.

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