Scientific realism and the history of science[1]

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Abstract

The paper considers the two main challenges to scientific realism, stemming from confirmation holism and the underdetermination thesis as well as from semantic holism and the incommensurability thesis. Against the first challenge, it is argued that there are other criteria besides agreement with experience that enable a rational evaluation of competing theories. Against the second challenge, it is argued that at most a thesis of local incommensurability can be defended that is compatible with a minimal version of scientific realism, namely conjectural realism. However, in order to establish a fully-fledged scientific realism, one has to refute the local incommensurability thesis as well, showing how a comparison is possible on the level of the proper concepts of the theories in question. The paper examines the prospects for such a comparison, distinguishing three cases.

1. Scientific realism

The purpose of this paper is to examine the challenge to scientific realism stemming from the history of science and to set out conditions that a fully-fledged defence of scientific realism has to meet. The paper first recalls the common definition of scientific realism (this section). It then considers the two main objections to this position, namely the underdetermination thesis and the incommensurability thesis. The paper argues that the underdetermination thesis does not block the possibility of a rational evaluation of competing theories (section 2). It then focuses on the incommensurability thesis, arguing that the standard externalist reply to that thesis manages to rescue scientific realism, but only a minimal version of that position (conjectural realism) (sections 3 to 5). In order to establish a substantial scientific realism, one has to refute the incommensurability thesis, showing that a comparison is possible on the level of the proper concepts of the theories in question. The last two sections of the paper consider the possibility of such a comparison, distinguishing three cases.

Scientific realism is commonly conceived as the conjunction of three theses – a metaphysical, a semantic and an epistemic claim (see, for instance, Psillos 1999, XIX–XXI). Let us fix these propositions in the following way:

(1) *the metaphysical thesis*: The existence and the constitution of nature are independent of our scientific theories. This independence is both ontological and causal: neither the

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existence of nature nor its constitution depend on whether or not there are persons who develop theories about nature. If there are persons who develop theories about nature, the existence of such theories does not cause the existence or the constitution of nature.

(2) *the semantic thesis*: The constitution of nature fixes which ones of our scientific theories are true (and which ones are not true). Consequently, if a scientific theory is true, the objects that it admits exist and their constitution makes the theory true.

(3) *the epistemic thesis*: Science is in principle capable of providing an epistemic access to the constitution of nature. In particular, we have methods at our disposition that enable a rational evaluation of the claims about the constitution of nature contained in different and incompatible scientific theories (or incompatible models or interpretations of a given theory).

The first thesis is not in dispute. The second thesis distinguishes realism from relativism (as well as from verificationism): the realist is committed to a non-epistemic notion of truth, whereas the relativist conceives truth as being relative to a conceptual scheme adopted by a community. The incommensurability challenge concerns the issue of realism vs. relativism in the first place. The third thesis differentiates in particular realism from empiricism: the realist is committed to maintaining that there are rational criteria of evaluating competing theories even if these theories agree in their empirical predictions, whereas the empiricist adopts an agnostic attitude in this case. The underdetermination challenge concerns the issue of realism vs. empiricism.

The third thesis is often spelled out in such a way that the realist subscribes to the view that our current scientific theories are true or approximately true and that the history of science manifests a development of theories that are more and more approximately true. However, it is not part of the definition of realism to settle the question to what extent it is justified to regard our current theories as true or approximately true. Even if our methods of evaluation established that our current and our past theories are very far from being true, one could maintain scientific realism, saying that we have not yet developed the best methods of scientific research.

2. Confirmation holism and the underdetermination challenge

Confirmation holism is the thesis that experience does not confirm or refute single propositions taken in isolation, but always a whole network of propositions or a whole theory. Confirmation holism goes back to Duhem (1914) – (English translation Duhem 1954; see part 2, chapter 6) – and Quine (1953). It is known as the Duhem–Quine thesis. The main argument is that whenever a single proposition is taken to be refuted by experience, there are background propositions available. There always is the logical possibility to change the truth-values attributed to some of these background propositions such that one can continue to hold on to the original proposition despite the recalcitrant experience. Confirmation holism therefore implies that theory is underdetermined by experience: for any given body of experience, it is logically possible to construct an indefinite number of theories that are incompatible with each other, but that are all in accordance with the experience – that is, it is possible to infer from each of these theories the observation propositions describing the experience in question.

Logical possibility, however, does not mean that there always are at least two rival theories that are equally credible. It is trivial that one can always construct a rival theory that is in accordance with the experimental data by *ad hoc* modifications of a given theory. This has no implications for the issue which theory it is *rational* to accept. One may construe the claims Quine makes in “Two dogmas” as meaning, among other things, that for any proposition, circumstances are conceivable in which it is *rational* to abandon the proposition in question in order to adapt a given system of propositions to new experimental data. The issue of whether or not it is rational to renounce certain propositions regarded as logical laws – such as the law of the excluded middle – to accommodate experience in the domain of quantum physics is a case in point (see Quine 1953, 43). However, this does not imply that for any given body of experience, we can conceive at least two rival theories that are both in accordance with the experience without there being any further rational criteria that distinguish one of these theories as a better candidate for a true theory than the other one(s) (see Laudan 1996, chapter 2, against any such claim based on underdetermination).

Whereas the history of science provides many examples of successor theories being incompatible with their predecessors, it is rare to find an example of two or more contemporary theories that contradict themselves in their ontological commitments, that make exactly the same experimental predictions and none of which is an *ad hoc* modification of a given theory. Quantum physics again is a case in point. Standard quantum mechanics as set out, for instance, in von Neumann (1932) – (English translation von Neumann 1955) – and Bohm’s rival theory – (first version Bohm 1952, last version Bohm & Hiley 1993) – make exactly the same empirical predictions. Nonetheless, there are at least two criteria that one can invoke in favour of a rational evaluation of any two such theories. First, if they agree in their experimental predictions at a given time, this does not imply that it is impossible to conceive an area in which the two theories may distinguish themselves by different predictions of experimental results (see Laudan & Leplin 1991, 451–455, reprinted in Laudan 1996, 56–59). For instance, in the case of standard quantum mechanics vs. Bohm’s theory, the domain of quantum fields may constitute such an area: it is an open question whether there can be a Bohmian theory that is equivalent to quantum field theory (but see Bohm, Hiley & Kaloyerou 1987 and Huggett & Weingard 1994, 382–387).

Moreover, if there are two rival theories that agree in their predictions of experimental results, they are rival theories because their ontological commitments are different. It is always possible to evaluate these commitments. Confirmation holism speaks against foundationalism in epistemology: experience is not a foundation of knowledge in the sense of being able on its own to justify scientific theories, for the same experience can be accounted for by rival theories. The logical possibility of such rival theories is sufficient to refute such a foundationalism. Confirmation holism therefore is linked to justification holism, that is, the view that a proposition is justified if and only if it is coherent with other propositions in a whole network of propositions (a whole theory). We can always employ the coherence criterion of justification holism to assess the ontological commitments of rival theories that agree in their experimental predictions. The coherence criterion examines two or more such rival theories against the background of our other knowledge, seeking to establish which one of these rival theories fits better into a coherent system of our knowledge as a whole. The idea behind that criterion is that explanation is linked to coherence: each of the rival theories seeks to explain a certain range of phenomena. These explanations, in turn, can be evaluated as to which one is more likely to be true, given what else we know about the world.

In this vein, the adherent to standard quantum mechanics can point out against the Bohmian that the quantum potential which Bohm's theory needs in order to reproduce the experimental predictions of standard quantum mechanics is a very implausible assumption against the background of our other physical knowledge – it is at least as implausible as the assumption of action at a distance that Newton's theory of gravitation implies. To counter that objection, the Bohmian, in turn, can point to the measurement problem into which standard quantum mechanics runs. (The question, however, is whether ontological assumptions such as those ones contained in Bohm's theory are necessary in order to solve that problem).

But what about two or more rival systems each of which is conceived as a complete theory of the world? One may think of an interpretation of quantum theory in the style of Everett (1957) according to which everything is a quantum system, subject to quantum entanglement, and no quantum state reductions occur, not even in measurement. There exists only one entangled quantum state of the world that includes all possible values that all properties can take as really existing in infinitely many different branches of the world. On the other hand, there is an interpretation of quantum theory that includes state reductions and thus a dissolution of entanglement (the most precise proposal in that respect goes back to Ghirardi, Rimini & Weber 1986). Consequently, there really are classical systems and classical properties having one precise numerical value in the world. Again, it is possible to evaluate and to compare the ontological commitments of any such rival complete worldviews. For instance, the worldview of universal quantum entanglement commits us to the view that each person has infinitely many minds, existing in different branches of the universe (see Albert & Loewer 1988 and Lockwood 1989, chapters 12 & 13). One may voice with good reason reservations about such an extravagant commitment.

Such an assessment of ontological commitments does not have to lead to an uncontroversial result that is accepted by all parties. There rarely are such results in philosophical debates. The interpretation of quantum mechanics again is a case in point. But this does not prevent philosophy from being a rational enterprise of evaluating the ontological commitments of different theories. Hence, the underdetermination challenge does not undermine the epistemic thesis to which scientific realism is committed. There is no need to accept only descriptions of observations and to remain agnostic about theoretical explanations.

3. Semantic holism and the incommensurability challenge

Apart from confirmation holism and justification holism, there is another form of holism that leads to another challenge to scientific realism: semantic holism. Quine puts this position forward together with confirmation holism in "Two dogmas". The main argument for semantic holism, however, goes back to Wittgenstein (1953a) – (English translation Wittgenstein 1953b) – and Sellars (1956). The basic idea is that the content (meaning) of a concept is given by its position in a whole network of concepts, that is, a whole theory. In short, the content of a concept consists in its inferential relations to other concepts (cf. Esfeld 2001, chapter 2). Semantic holism is widely accepted at least with respect to theoretical concepts. For instance, the concept "electron" cannot be introduced by pointing to electrons. It is introduced by indicating its inferential relations to other concepts in a whole theory. The theory as a whole then has certain observational consequences. To take another example, an example of a common sense concept, according to semantic holism, the content of the concept of water consists in inferential relations to the concepts of liquid, odourless, colourless, thirst-quenching, etc.

Semantic holism implies that there is no separation between issues concerning factual matters and issues concerning conceptual content (meaning). Changes in our views as to what the world is like go together with changes in conceptual content. The reason is that a theory change entails a change in some inferential relations – that is, according to semantic holism, a change in conceptual content. For instance, in Newton's theory, gravitation is conceived as a force that acts at a distance. In other words, there is an inferential link between the concept of gravitation and the concept of action at a distance. In general relativity, by contrast, gravitation is conceived as an effect of the curvature of space-time. Hence, the inferential link from gravitation to action as a distance is cut off and replaced with a link from gravitation to space-time curvature and effects that the latter has. Another prominent example is the change in the content (inferential relations) of the concept "electron" from prescientific theories via classical field theory to quantum mechanics. Examples such as these ones are taken to show that there can be a radical conceptual change when one theory is replaced with another one.

Such examples drive the claim of semantic incommensurability put forward by Kuhn (1962, chapters 9 & 10) and Feyerabend (1962), which is based on semantic holism. For instance, the concept of gravitation as action at a distance is incommensurable with the concept of gravitation as an effect of space-time curvature, because these two concepts do not have any significant scientific inferences in common. There is a radical conceptual change from Newton's theory of gravitation to Einstein's theory of gravitation: the language of general relativity does not even have the conceptual means at its disposal to express the idea of an action at a distance. In this sense, Newton's concept of gravitation cannot be translated into general relativity.

Despite this radical conceptual change, there is a cumulative progress from classical physics to relativity physics and quantum physics on the level of the empirical predictions. But that progress does not hinder that the older theories are false: all the predictions of experimental results of any theory of classical physics before the 20th century are strictly speaking false. Nonetheless, the difference between these predictions and the predictions derived from our current physical theories is in many cases negligible: no measuring instrument that we have at our disposal can detect that difference. Our current theories thus account for the empirical successes of the older theories. They make intelligible why the older theories continue to be applicable in many cases for all practical purposes. That notwithstanding, our current theories imply that the older theories are false. The explanations they contain are beside the point. Gravitation is no action at a distance, there are no classical point particles, there is no simultaneity independently of a reference frame, etc. Hence, continuity, amounting to cumulative progress as regards the predictions of experimental results, goes together with a radical change in the explanations of the experimental results. That radical change is taken to amount to the incommensurability of at least some of the proper concepts of our current theories with the corresponding concepts of their predecessor theories.

The thesis of semantic incommensurability is a challenge to scientific realism. This thesis calls into question whether there is progress on the level of explanation, that is, on the level of our views about the constitution of nature. The explanations of the classical physical theories before the 20th century are known to be false. What reason do we have to regard our current explanations as being true – or at least as coming closer to the truth – than their now abandoned predecessors? Kuhn goes as far as suggesting replacing the idea of science making cognitive progress with the idea of changes of scientific theories not being directed to any goal (1962, chapter 13). Incommensurability thus is gist on the mills of what is known as the argument from pessimistic meta-induction (Laudan 1981 and 1984, in particular 157), although that argument as such is independent of the incommensurability thesis: our past theories have turned out to be false. There is no reason to suppose that our current theories will endure a better fate. We are thus not justified in supposing that there is cognitive progress in the history of science.

There is an easy Popperian answer to that argument: most of our past theories have indeed been falsified. But falsification is the means to make cognitive progress. By replacing our old theories with new ones we correct the errors that the old theories contain. We make cognitive progress in the sense that we come closer and closer to the truth about the constitution of nature by falsifying our old theories and replacing them with new ones (see Popper 1959, in particular chapters 4 & 10). This Popperian reply presupposes, however, that the newer theories do not only improve on the older theories as regards the range and the accuracy of predictions, but also that the theoretical explanations which the newer theories offer are comparable with the ones of the older theories. The explanations of the newer theories are surely incompatible with the ones of the older theories: they contradict them. Nonetheless, it is possible to compare the proper concepts of the newer theories with the proper concepts of the older theories. Being in a position to carry out such a comparison is a necessary condition for being able to argue that we come closer and closer to the truth through falsification. Otherwise, there would only be a theory replacement, but no continuous progress towards truth. It is here that the argument from semantic incommensurability comes in: that argument seeks to establish that this presupposition of comparability is not satisfied.

4. The externalist reply to the incommensurability challenge

The standard reply to the incommensurability challenge consists in pointing out that semantic holism is not the whole story about conceptual content. There also is reference. For the claim of semantic incommensurability to have a substantial content, it has to be presupposed that any two theories whose proper concepts are incommensurable share a common referent. That is to say, they are either identical in extension, or the extension of the newer theory includes the extension of the older theory, or at least there is a considerable overlap in the extensions of the two theories. It would be pointless to claim, for instance, that the proper concepts of Darwinian evolutionary biology are incommensurable with the proper concepts of quantum cosmology, for these theories apply to entirely different domains. What is interesting is the claim that theories of the same domain can nevertheless employ concepts that are incommensurable with each other.

Externalism in the philosophy of language as set out notably by Putnam (1975) seeks to include the real constitution of the referent of a concept into the content of the concept in question. Thus, for instance, the content of the concept "water" does not only consist in the inferential links to the concepts of liquid, odourless, colourless, thirst-quenching, etc., but it also includes that water is H_2O – even if the persons who employ that concept ignore the real constitution of water. Putnam's claims sparked a discussion that continues to date. One can sum up the current state of the art by using the framework of two-dimensional semantics. This framework introduces a distinction between two components of conceptual content, the primary intension and the secondary intension (for an overview and introduction, see Chalmers 1996, 52–71; for the current discussion, see the papers in *Philosophical Studies* 118 (2004), issue 1).

The primary intension of a concept is its inferential role in a given language or theory. The primary intension yields as referent of the concept whatever satisfies the description in which the inferential role consists – such as the description of "odourless, thirst-quenching liquid, etc." for "water" and H_2O as the referent of that description in the actual world. The secondary intension takes the reference of the concept in question to be fixed by its extension in the actual world and regards that extension as invariant across all possible worlds (that is, all possible situations). Thus, the extension of "water" are all and only those things that are H_2O – even if, in other possible worlds, things of another chemical composition come under the description in which the inferential role of our concept "water" consists. What is relevant here is that incommensurability can concern only the primary intension; only the primary intension changes as our theories change. The secondary intension is invariant.

Putnam's original motivation in setting out semantic externalism was to use this theory of conceptual content as a tool in order to overcome the challenge for scientific realism that incommensurability poses. In Putnam (1973), he maintains that the sameness of reference of incommensurable concepts ensures that the theories in question can be compared on the basis of their common – or at least overlapping – extension. Based on the undisputed superiority of the successor theory as regards predictive success, this enables us to establish according to Putnam that the successor theory makes a cognitive progress over the predecessor theory, offering an account of the real constitution of the referent that comes closer to the truth.

However, as has been acknowledged in the literature following Putnam's original suggestion, there is no reference without description. The main claim of semantic externalism with respect to reference can be construed in the following way: it is possible to refer to something without being able to indicate necessary and sufficient conditions that distinguish the thing in question from all other types of objects. For instance, one can refer to beech trees without being able to give a description that tells a beech from an elm (example of Putnam 1975, 226–227). In the same way, one has to be able to describe some characteristic effects or other of water or electricity in order to be able to refer to water or electricity.

If there is no reference without description, it follows that we need a description in order to identify a referent that is common to two incommensurable theories. This has to be a description that is exempt from the alleged incommensurability that affects the proper concepts of the two theories in question. In other words, for any two incommensurable theories, there has to be a description of a common referent of these theories that is neutral with respect to the controversy between these theories. It is only necessary that the description is neutral with respect to the controversy in question. There is no need to call for a description that is neutral in an absolute sense (such as the idea of an observation language that is neutral with respect to any theory). In many cases, the language of common sense can be construed as providing for such a description. For instance, the description of water as a liquid that is odourless, colourless, thirst-quenching, etc. is sufficient to refer to water, indicating some characteristic effects of water, and neutral with respect to the controversy between a theory of water as a primitive substance and a theory of water as being composed of atoms (or molecules for that matter). Any theory of water, however, has to be such that the common sense description of water can be deduced from it if it is to be in accordance with experience.

As regards theoretical entities beyond common sense – such as electrons, for instance – one can maintain that the knowledge of characteristic effects of these entities that the experimenter has to possess in order to be able to manipulate these entities constitutes a description that is neutral with respect to the controversies in which the theoretical physicists and the philosophers of science are engaged. One can invoke the movement known as new experimentalism to make that point. As notably Hacking (1983) has stressed – (in particular chapter 16, originally published as Hacking 1982) –, in order to do experiments with electrons, the experimenter does not have to take a stance in the controversy between, for instance, the Copenhagen school and Bohm's theory. He does not even have to know what this controversy is about – as long as all the theories that are touched by this controversy agree in their predictions of experimental results and their instructions how to set up experiments with electrons.

The commitment to a neutral description does not contradict semantic holism. The primary intension of the concepts that this description employs consists in an inferential role, that is, inferential relations to other concepts. These are, however, concepts that do not imply any of the concepts that are touched by the controversy in question. In other words, these concepts are not specific enough as yet to imply the one or the other of the theoretical explanations. Semantic holism is not the absurd thesis that the content of any concept depends on the content of all other concepts, but the – reasonable – thesis that content in the sense of the primary intension of any concept consists in inferential relations to other concepts. Functionalism has shown us how to analyse the primary intensions of many concepts in terms of inferential relations to other concepts without thereby being committed to a particular view about the underlying, real constitution of the referents of these concepts (that is, their secondary intensions) (cf. for instance Lewis 1972).

The externalist reply does not refute the thesis of semantic incommensurability. It tries to tame that thesis. If conceived in the sketched framework, semantic incommensurability turns out to be a moderate claim that is compatible with scientific realism and the rationality of science. There is only question of a local incommensurability between some of the proper concepts of two or more theories that share a common referent. There always is a description of that common referent available that is neutral with respect to the controversy in which the two theories are engaged. On this basis, it is in principle possible to compare any two rival theories and to establish which of them is the more credible candidate for a correct description of the constitution of the referent and, thus, which one is the better candidate for a correct explanation of the experimental data (as regards replies to the incommensurability challenge along these lines, see Bartels 1994, in particular chapter 1, Sankey 1994, in particular chapters 6 & 7, and Carrier 2001).

In publications following the first edition of *The structure of scientific revolutions* (1962), Kuhn can be regarded as maintaining no more than the mentioned local incommensurability (see, in particular, Kuhn 1983, 670–671). Feyerabend, by contrast, has radicalised his position in the publications following his first paper on incommensurability (Feyerabend 1962). He is considered to be one of the main proponents of a claim of global incommensurability according to which whole worldviews are incommensurable with one another such that no neutral description of a common referent is possible (see in particular Feyerabend 1975, chapter 16). Replacing one scientific theory with another one amounts to changing a whole worldview so that in the last resort the content of all concepts, including the ones of common sense, is affected by a theory replacement in science.

The thesis of global incommensurability is committed to the view that there are several perspectives on the world in the sense of conceptual schemes. These perspectives or conceptual schemes are incommensurable with each other. Therefore, no rational evaluation is possible across claims conceived in different conceptual schemes. This position amounts to relativism, rejecting the semantic thesis in the definition of scientific realism. There is not a binary relation of truthmaking between what there is in the world and propositions, but truth is relative to a conceptual scheme. Relative to one conceptual scheme, certain propositions are true, relative to another conceptual scheme, other propositions are true, and the schemes are incommensurable with each other.

There are strong objections from semantics against the thesis of global incommensurability. Davidson (1974), in particular, has argued that the notion of a perspective in the sense of a conceptual scheme is not intelligible. In any case, the thesis of global incommensurability cannot be built on semantic holism. It contradicts the main motivation for semantic holism as set out by Sellars (1956) and Davidson himself (see in particular Davidson 1983). Semantic holism, as conceived by Sellars and Davidson, is opposed to the view of an epistemic intermediary – such as a conceptual scheme – intervening between our concepts, beliefs, or theories and their referents in the world (Sellars 1956 denounces any idea of such an intermediary as “myth of the Given”). For Sellars and Davidson, the whole point of conceiving content as consisting in inferential relations (instead of being relative to such an epistemic intermediary) is that this conception opens the way to maintain that our concepts, beliefs, or theories are directly related to what there is in the world and that the constitution of their referents is the truthmaker for our beliefs and theories (cf. Esfeld 2001, chapters 4 & 5).

Moreover, semantic holism, as conceived by Sellars and Davidson, implies that when certain of our beliefs or theories change, there is a change in content in the sense that some of the inferential relations that constitute the content (primary intension) of a concept change. In short, changes in our views about facts go together with changes in conceptual content. However, any such change is only partial, being intelligible only against the background of a lot of inferential relations that remain unchanged. Hence, although semantic holism constitutes the philosophical background of incommensurability, a claim as radical as global incommensurability cannot be justified on the basis of semantic holism. On the contrary, one can derive an argument against global incommensurability from semantic holism.

In sum, local incommensurability is compatible with scientific realism. Global incommensurability amounts to relativism. But global incommensurability does not constitute a challenge that is worth of being taken seriously, for lack of a sound argument.

5. *Conjectural realism*

However, there is a drawback. The externalist reply to the incommensurability challenge is able to vindicate only a minimal version of scientific realism that one may call conjectural realism (as regards that term, see Worrall 1982, 202, 227–231): today’s theories are the best rational conjectures that we can currently make as regards the constitution of nature. They definitely are better conjectures than our past theories, which are known to be false. The cumulative progress on the level of empirical predictions together with the externalist reply to

Kuhn's and Feyerabend's claims is sufficient to establish this point. Today's theories constitute a progress in comparison to our past theories as regards the discovery of the constitution of the referents of these theories. Thus, for instance, it is a better conjecture concerning the nature of gravitation to say that it is an effect of space-time curvature than to maintain that it is a force that acts at a distance. In short, conjectural realism acknowledges that we have methods at our disposition that enable a rational evaluation of the claims about the constitution of nature contained in different and incompatible scientific theories (see the epistemic thesis in the definition of scientific realism set out in section 1).

Nevertheless, according to the externalist reply to the incommensurability challenge and conjectural realism, the comparison between the predecessor theory and the successor theory is situated only on the level of the referent that both these theories share. If the proper concepts of the two theories are incommensurable, it is not possible to establish a direct comparison between their concepts. There is no sense in which the proper concepts of the predecessor theory come close to or can be integrated into the concepts of the successor theory. For that reason, the argument from pessimistic meta-induction has the following bearing in this context: it is likely, given the history of science, that the theories that today are our best conjectures will be superseded in the future by other theories. If, as a general rule, the proper concepts of the predecessor theories are incommensurable with the proper concepts of their successor theories, it is likely that the proper concepts of our future theories will be incommensurable with the proper concepts of our current theories. Consequently, it is possible that our current theories may be true or approximately true, but given the theory replacements in the history of science, we do not have any reason to believe in their truth or approximate truth. One cannot maintain that the proper concepts of our current theories are closer to the proper concepts of a true and complete theory of the domain in question and that the proper concepts of a future theory will come even closer to those concepts. One conceptual framework of explanation of the phenomena is simply replaced with another one.

Hence, the thesis of local incommensurability is compatible with a minimal version of scientific realism that one may call conjectural realism. But this is not a substantial and satisfactory scientific realism, because this position implies – by way of the argument of pessimistic meta-induction – that we do not have any reasons for believing that our current theories are true or approximately true. If one wishes to maintain a scientific realism that includes such reasons, one has to refute the thesis of incommensurability, even in its moderate, local form. One has to establish a comparison between the proper concepts of the theories of the same domain that succeed one another in the history of science.

6. *The reconstruction of the formalism*

There is not only cumulative progress on the level of empirical predictions despite theory change. There also are precise logical relations between the formalisms – that is, the mathematical equations – of any major mature physical theories that succeed each other in the history of science. It is well known that the formalisms of the main mature classical physical theories before the 20th century can be reconstructed from the formalisms of their successor theories in relativity physics and quantum physics. More precisely, it is possible to derive within the formalisms of the newer theories an image of the formalisms of the older theories that reproduces the predictions of the older theories in the cases where one can neglect certain quantities: if one carries out a mathematical operation that lets the quantum of action approach zero ($h \rightarrow 0$) or a mathematical operation that lets the velocity of light approach infinity (so that $1/c \rightarrow 0$) one can reproduce within quantum mechanics or special relativity the predictions of classical mechanics. The situations in which classical mechanics is applied successfully are such that one can for all practical purposes proceed as if the quantum of action were zero or as if the velocity of light were infinite; the systems dealt with are very big in comparison to the quantum of action, and the velocities are very small in comparison to the velocity of light. In fact, the matter is more complicated and requires a detailed mathematical examination. These examples are only meant to give a rough idea of how one seeks to reconstruct the formalism of classical mechanics from the formalisms of its successor theories. This possibility to reconstruct the formalism of classical mechanics explains why the predictions of classical mechanics are successful in certain areas.

Some philosophers take the possibility of such a reconstruction of the formalism of the older theory from the formalism of the newer theory to be a sufficient basis for claiming that the concepts of the older theory can be integrated into the concepts of the newer theory. They go as far as maintaining that the older theories are reduced to the newer ones (see, in particular, Schaffner 1967, Hooker 1981, part I, § 3, and 2004, sections 1–3). However, that conclusion cannot be warranted on this basis alone. The formal structure of the newer theories is very different from the one of the older theories. Special relativity, for instance, is fundamentally distinct from its predecessor theories in posing the principle that the velocity of light is finite and constant, independently of any reference frame. The same goes for quantum mechanics in comparison to classical mechanics; that is why quantum mechanics, in distinction to classical mechanics, raises a number of notorious problems of interpretation. The fact that the formal structure is considerably different means that there is a great difference on the level of the explanations that both theories offer. What is therefore needed is not only a reconstruction of the formalism, but also a reconstruction of the concepts of the predecessor theories from the concepts of the successor theories.

7. *The reconstruction of the concepts*

To refute the thesis of a radical conceptual change, amounting to semantic incommensurability, it is sufficient to show that the concepts of the older theory can be reconstructed on the basis of the concepts of the newer theory. There is no general rule how to do that. The examples of major theory replacements in physics that we have mentioned so far allow us to distinguish three cases.

(1) Consider the example of classical mechanics and quantum mechanics. Assume a version of quantum mechanics that includes a dynamics which leads to definite numerical values as measurement outcomes (the most elaborate proposal in that respect goes back to Ghirardi, Rimini & Weber 1986). In that case, quantum theory includes the description of a transition from quantum states, characterized by superpositions and entanglement, to classical states. There is of course a considerable conceptual change from classical mechanics to quantum mechanics. But this change does not amount to semantic incommensurability. The change concerns the view of the fundamental level of nature. Quantum mechanics shows that the assumptions of classical mechanics about the fundamental level of nature are false; nonetheless, classical concepts can be derived within quantum mechanics, having a limited domain of applicability: they apply as soon as quantum superpositions and entanglements are dissolved, and quantum mechanics, on the version elaborated on by Ghirardi, Rimini &

Weber (1986), includes a dynamics for this dissolution (state reductions). Generally speaking, this is a case where the concepts of the older theory can be integrated into the concepts of the newer theory, having a limited domain of applicability within the domain that the newer theory covers.

(2) The case is different if one maintains a version of quantum mechanics that does not acknowledge definite numerical values as measurement outcomes so that there are no state reductions. Instead, everything that there is in the physical world is subject to quantum entanglement, and there is only a universal quantum state of the world (that version, which is based exclusively on the Schrödinger dynamics, goes back to Everett 1957). Definite numerical values of physical quantities as measurement outcomes are merely the way in which the world appears to a local observer whose cognitive access is confined to a particular branch of the universe. Definite numerical values as measurement outcomes – and classical properties in general – are relative to a certain state of consciousness of a local observer. Apart from that particular branch of the universe, there are infinitely many other branches of the universe in which other numerical values of the physical properties in question exist relative to other states of mind of the observer. The universal quantum state of the world includes all these branches (cf. Albert & Loewer 1988 and Lockwood 1989, chapters 12 & 13).

In that case, there is no domain of the world to which the concepts of classical physics apply, for there is nothing that is not subject to quantum entanglement. The explanations that classical physics offers are false and beside the point. Nonetheless, one can reconstruct the concepts of classical physics on the basis of the concepts of quantum theory. Given the universal quantum state of the world that includes infinitely many different branches of the world in which the same physical systems exist in different relative states, one can reconstruct the concepts of classical physics as describing how the world appears to a local observer. The mistake of classical physics is to take that appearance for the physical reality. Generally speaking, given the wider conceptual framework of the successor theory, one can reconstruct the concepts of the predecessor theory within that framework, although these concepts do not yield any true or approximately true explanations of what there is in the world. Instead, they describe how the world appears to a local observer with limited cognitive access.

The case of classical mechanics and special relativity is in a certain manner conceptually similar. If the velocity of light were infinite, the distinction between events that are separated from each other by a spacelike interval, by a timelike interval and by a lightlike interval would collapse. Spatial and temporal distances, including notably the relation of similarity between events, would no longer depend on a frame of reference. However, given that the velocity of light is finite and constant, there is no domain to which the spatio-temporal concepts of classical mechanics apply, and the explanations employing these concepts are all false. Nonetheless, one can reconstruct the spatio-temporal concepts of classical mechanics within the framework that is given by the principle of the velocity of light being finite and constant, showing how these concepts describe how the world appears to an observer within a given frame of reference. The observer takes these concepts to be objective, not realizing that they depend on a frame of reference (that is privileged for her, but not privileged in a general manner).

(3) Consider the case of Newton's theory of gravitation and general relativity. Although the predictions nearly coincide within a certain domain, there is no possibility to reconstruct

within general relativity the concept of an action at a distance. It is not possible to reconstruct that concept as describing how the world appears to a local observer. That concept describes a consequence to which Newton's theory of gravitation is committed; it does not belong to the repertoire of a local observer. In short, the view of there being an action at a distance is simply abandoned and replaced with a theory of curved space-time according to which gravitation is an effect of space-time curvature.

To vindicate scientific realism in view of such examples, one can argue that the abandoned concepts do not belong to a mature scientific theory. It is well known that Newton himself considered action at a distance to be an absurdity (see letter 406 to Bentley, 25 February 1692/3, in Newton 1961, 254). One may therefore try to argue that the implication of action at a distance to which Newton's theory of gravitation is in fact committed is an anomaly, showing that this theory cannot be correct by Newton's own lights.

In none of the three types of cases considered, the concepts and explanations of the predecessor theory come close to or approximate the concepts and explanations of the successor theory. Furthermore, all these cases are much more complicated than is suggested by the mathematical operation of letting a particular quantity approach zero in order to derive an image of the formalism of the old theory within the formalism of the new theory. The reason is the difference in the formal structure of the successor theories in comparison to their predecessors. Even in the case of quantum mechanics and classical mechanics, there is no question of a simple transformation of the reconstruction of the formalism into a reconstruction, or even a reduction, of the concepts. Everything depends on the way in which one interprets quantum mechanics.

Nonetheless, only the third type of case is a case of semantic incommensurability. The thesis that semantic incommensurability is widespread is unfounded. The first type of case is a case of theory reduction: if quantum mechanics includes a dynamics for a transition from superposed or entangled quantum states to classical states, then it is possible to reduce classical mechanics to that version of quantum mechanics; for it is then possible to derive within quantum mechanics concepts that match the role (inferential relations) of the proper concepts of classical mechanics within a certain domain. The second type of case is situated somewhere in between: there is no domain in which the concepts of the predecessor theory truly apply or are approximately true, but it is possible to reconstruct the concepts of the old theory within the framework of the new theory, namely as describing how the world appears to observers with a limited cognitive access.

Already the second type of cases can be regarded as being sufficient to ground the claim that there is not a simple theory replacement in the history of science, but that the successor theories come closer to the truth than their predecessor ones (although we do not have at our disposal a universally accepted, precise definition of the notion of coming close to the truth). One can maintain that there is an approximation to a true and complete theory of the domain in question – or even nature as a whole – in the following sense: the common cases of replacing the old theories with new ones amount to an enlargement of our point of view, because it is to possible to reconstruct within the new theory the proper concepts of the old theory as describing the way in which the world appears to a local observer with a limited cognitive access. In replacing our old theories with better ones, we reduce the limits of our point of view, coming closer to an objective description, that is, a description and explanation of the world from a point of view from nowhere. Scientific realism is the ambitious project of transgressing our cognitive limits, given that we are finite thinking beings confined to a very small spatio-temporal region of the universe, seeking to reach an objective description of the world.

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