Science and reality

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Since the heyday of logical positivism, the dominant view in philosophy of science has been Realism. But over the last two or three decades its prominence seems to decline. No one wants to return to the excesses of logical positivism, but as the dust after the battle settled, it became more and more clear that not everything the defeated part stood for was without merit. And, as we shall see, Realism has its excesses and problems too. Hardcore instrumentalists believed that the scientific theories are mere tools for predictions and calculations and that they contain no content telling us how the world really is, being conceptual tools that are neither true nor false. Theories help us to organize empirical data in virtue of the claim of theoretical entities, but theoretical entities are, and always will be, fictitious mental constructions because their alleged existence would transcend anything that could be established by sense experience.

Realism grows out of the practical and observational success of science itself. Instrumentalism, in contrast, is generated by a philosophical desire to strip metaphysics of any veil of legitimacy and to dress science in armour of epistemic warrant. As long as astronomy, physics, chemistry and biology dealt mainly with macroscopic objects which could be observed, as was the case to the end of 19th century, the acceptance of the instrumentalist view had no far-reaching implications, neither with respect to the number of theoretical entities explained away, nor with respect to possible technological consequences of a belief in these entities. But with the development of new theories about invisible entities, forces and processes such as electric and magnetic fields, molecules, and atoms, and together with the rapid increase in technology based on our beliefs in such entities and processes, it seems pointless to push the claim that we do not possess knowledge of that part of reality which is not directly accessible to the naked eye. It is, the realist would say, only because scientific theories provide us with knowledge of the hidden structure behind phenomena that we have been able to change nature, design new organisms, and improve the material and technological level of modern society. Science does not merely yield theories that predict how well-existing phenomena may change. It also fosters theories that give us insight into the laws of nature – thus allowing the creation of quite new phenomena never seen before. As Hilary Putnam once declared: realism is the only philosophy which does not consider the empirical success of science a miracle.

In this paper I shall take issue with some of the most common arguments in favour of scientific realism. My aim is to show that "theory realists" who advocate *semantic realism* have not presented convincing arguments for their thesis that currently accepted theories must be true or approximately true if we shall be able to explain their empirical success. Similarly, I hope to demonstrate that an alternative form of scientific realism, *structural or syntactic realism*, which is very much in vogue, is no way out for the realist. Rather than being a realist concerning theories I share company with those philosophers who are realists concerning entities.

1 Ontological commitments

Realism is a possible position in many different fields. In case one believes that the external world exists independently of our consciousness regardless of whether one believes in its existence or not, one is a realist with respect to the surrounding reality. Or in case one is in favour of the idea that there are moral facts which are not, in some way or another, determined by people's sentiments and emotions, one is a realist with respect to what is right and wrong. Or if one takes the view that abstract entities such as numbers exist, even though they are not provable or constructible, one will be a realist concerning mathematical quantities. We can also be realists when it comes to kinds, universals, modalities, and possible worlds. Common to every realist concerning these different areas is that what he is a realist about is taken to be real, regardless of whether he himself or other human beings had existed. But it is not a requirement that if somebody is a realist in one area, he must be so in every other area. Thus, there is no implication between a belief in the objective existence of the external world and a belief in, say, the independence of moral values.

Nonetheless, since one can be a realist with regard to truth too, the obvious question is whether or not one can be a realist in some areas without being a realist with respect to truth. Before answering this question, we shall throw more light on the realist view that entities exist objectively, independent of our knowledge of them. For the matter of focus we shall restrict the discussion to the problem of the reality of the external world.

As a start, let us turn to the realist claim of mind-independence. Here the realist may have two ideas in mind. The first is that the external world exists objectively, which must be taken to mean that the world is what it is independently of human consciousness. The objective world is not constituted by our knowledge of it; space, time, things, events, properties, and laws of nature may exist whether we believe that they do or not. These entities may be real, even though they are not objects of our perception. The second idea is that the objective world is a physical world. It does not consist of experiential objects like sense-data or other mental objects. The realist hereby also makes the external world physical, or mostly physical. Indeed, a realist is not prevented from submitting that the mental is different from the physical, nor therefore from claiming that the mental is objectively real, independent of whether someone believes it or not. Realism does not rule out objects like minds, but it claims that the existence of minds and their specific nature are what they are regardless of the way one actually may conceive and apprehend them, and regardless of whether they are objects of anybody's apprehension. Thomas Nagel, for instance, believes that there are subjective facts which are unattainable to human knowledge (Nagel, 1974). The requirement of logical independence of human knowledge also means that things, events and laws can exist even if they cannot be known, that is, even if they are, in principle, empirically inaccessible. The realist must agree upon the possible reality of such entities. The world may be inconceivable to our mind. Nothing in his metaphysical point of departure excludes the existence of unknowable entities as a genuine possibility.

Another aspect of the realist's thesis is the question of existence. What is it that is real? Assuming that the realist is bound to assume that the external world exists the way it does, irrespective of whether it is empirically accessible or not, it means at least that the world is what it is in itself. Whether or not we are capable of understanding the external world such as it is in itself, is not a question which excludes that it is what it is in virtue of itself. Reality is not just what it is as a result of our way of apprehension. The external world is both structured and ontologically determinate or unstructured and ontologically indeterminate, but whatever it is, it is what it is prior to our knowledge of it. But the realist is not required to believe more than that. He is not forced to believe anything specific about the world's organization. He may, for instance, contend that the world in itself consists in those things which surround us in our ordinary life. The physical world as we perceive it is the world as it is in reality. The world in itself consists of stuff and objects like gold, water, human beings, animals, cars and refrigerators. This view could be called the *everyday version* of Realism. The realist may also hold that the common sense view of reality has to be supplemented with the scientific story about laws and unobservable things and properties, a position which shall be called the *tolerant version* of Realism. Finally, the realist can take a step further. He may deny completely that reality is what it is considered to be on the basis of our ordinary experience. Instead he can argue that the real world is as science tells us. The later formulation may be called the *intolerant version* of Realism. This is the view Kant scornfully called transcendental realism. Whether the realist adopts the tolerant or the intolerant version, he holds a view to which scientific theories narrate about a reality hidden from our immediate senses: the world is furnished with different kinds of particles and forces impossible to see with our naked eye and which do not possess the same properties as those being ascribed to perceptual things.

Setting the various versions of Realism aside for the moment, what arguments can be levelled in support of Realism in general? Many will probably agree with Thomas Nagel when he points out that if we look at our history, we see that at some time our ancestors did not know, or were not able to conceive, aspects of reality which we know or can conceive today (Nagel, 1986, ch. 6). Similarly, there are things we cannot now grasp, but will be able to later. From these observations, most people will accept an inference to the conclusion that there may be things we cannot conceive of at a particular time in the future, and therefore never ever come to understand. The decisive factor is, of course, whether this means that there are things of which we have no conception because of the way we and these things are, and not because we are at too early a stage of our history. Here the waters divide between realists and antirealists. For the realist would argue that even now some people lack a capacity to conceive of colours or sounds if they are born blind or deaf. And some people don't have the mental power to understand quantum mechanics or the general theory of relativity. Analogously, we can imagine that there are aspects of the world which nobody, in principle, is able to think or know about. The antirealist, on the other hand, would dispute this argument by saying that our thought cannot reach beyond the conditions for the possibility of thoughts. We can make sense of the examples of the disability of the blind, the deaf, and the person with a low mental ability to see, hear or understand aspects of the world only because we realize that other people have the ability to know or conceive them. In other words, the antirealist believes that the examples make sense since we already have a language in which these features are fully specifiable. We cannot, according to him, claim to have a general concept of reality based on what we know or comprehend already, and then meaningfully apply it to something which is incomprehensible.

This dispute cannot be addressed further until we know more about what sets the boundaries of our thought and how truth relates to sentences expressing our thoughts. But Nagel mentions that in our notion of a universal or an existential quantification, the value of a variable need not have to be the referent of a specific name or description in our language (Nagel, 1986, p. 98). The reason is that we already have a general concept of everything which comprises both what we can name or describe, and what we can't. Consequently, we can speak of 'All the things we can't describe imagine or conceive of owing to our very nature.' For this claim to become a way out for the realist, it seems as if he must admit that such a sentence can be true only if there is a negative fact making it true. So long as the realist talks negatively about something which is known, say, ‘The Eiffel Tower is not made of wood’, a statement like this does not require the existence of a negative fact that the Eiffel Tower is not being made of wood to be true. What makes it true is the positive fact that it is made of steel. If it is completely made of steel, it cannot also be made of wood. In the case of the sentence concerning everything we can’t describe, the realist does not have the same opportunity to state which positive fact makes the negative sentence true. Thus, if this consideration is true, it raises serious doubts about the realist’s claim that the general concept of reality he applies to what humans cannot understand is the same as the one he uses for what is conceivable by us.

The metaphysical account of realism as regards the external world has so far provided us with three more precise claims: 1) physical things which we experience immediately through our senses exist objectively in some way or another irrespective of our beliefs in them; 2) theoretical entities which are not objects of direct sense experience, but which are related to our best scientific theories, are real and not merely mental constructions; and 3) the best scientific theories tell us how the world is. Nevertheless, it is not uncommon to hear an objection against this metaphysical account of realism. The complaint at this is point is that realism in terms of a mind-independent world is obscured by metaphorical language. Is it possible to specify the realist’s position further? Perhaps not. A possible supplement would be to say that realism with respect to the external world also implies a semantic formulation: if the world does not necessarily square with our cognitive resources, then sentences about physical laws and objects are not reducible to sentences about mental states. The former type of expressions has a meaning which cannot be translated into expressions of the latter type. For example, according to common sense realism, sentences about the external world are not translatable into sentences about sense-data, the truth of physical-object statements cannot be expressed in terms of the truth of statements concerning mental states or subjective experiences. I am not claiming that this semantic formulation is logically equivalent with the ontological formulation of the mind-independent thesis. What I am saying is that for the realist the mind-independent thesis has to be associated with the untranslatable thesis to be intelligible, and this holds for scientific realism as well as for common sense realism. Even though the realist would admit the possibility of some unknowable entities, he cannot claim without serious difficulties that the reality-in-itself is completely unknowable, and therefore that our language does not concern such a mind-independent world. Though logically possible it is difficult for the realist to argue positively for the existence of a reality *an sich* and at the same time hold that this reality could be cognitively inaccessible in principle. Because how could he ever know its existence? The common-sense realist would most likely assume that we are not prevented from having knowledge of the reality of the things in themselves and that this knowledge can be expressed in physical-object sentences. Consequently, the scientific realist can semantically be characterized as one who argues that: (i) statements about theoretical entities cannot be reduced with respect to truth conditions to statements about what we can perceive, and (ii) sentences concerning laws of nature cannot be reduced with respect to truth conditions to sentences about their physical manifestation.

Based on the above discussion, we may define Realism as a general metaphysical doctrine consisting of four components. First, there is the *ontological* component of the view: whatever there is is what it is regardless of how we think of it. A real entity, or a law of nature, has full, concrete specificity and determinateness, or lacks both, independently of our mental powers. The realist is not forced to argue that determinateness holds good for the world as a whole. For instance, instead of maintaining that the future (and the past) is ontologically determinate, he could claim that the future (and the past) is ontologically indeterminate or simply unreal. Likewise he could argue that quantum objects are vague or fuzzy entities which have indeterminate attributes. This leaves, apparently, the realist with three different options concerning the nature of the mind-independent world. First, he can hold that everything real is ontologically determinate in the sense that it has concrete specific attributes; second, he can hold that at least a part of what is real is ontologically indeterminate in the sense that it lacks actuality and attribute specificity; and third, he can argue that parts of the world are unreal in the sense that nothing exists corresponding to certain thoughts or imaginations.

Although reality in itself according to the realist exists entirely detached from our cognitive capacities, it is generally assumed that those physical-object statements and/or scientific statements we use in our communicative discourse refer to such a mind-independent world. Thus the claim of the existence of a mind-independent world is associated with a thesis that the true common sense account and/or the true scientific account concerns the objective reality as it is regardless of our senses, opinions, and emotions. An important consequence of the thesis is that statements about the world are not reducible to statements about anything else, especially not to statements about our subjective experience or mental states of the mind. However, according to the intolerant version of scientific realism, as defined above, it is possible to reduce the ordinary physical-object language to the language of science without any loss of meaning.

Second, there is the semantic aspect of the view: the meaning of statements about the external world must be analyzed by reference to the notion of truth conditions whose specification in principle may reach beyond any possible empirical justification. A sentence is true or false independently of whether or not we have any means to verify or ascertain its truth value. What determines these truth conditions is an alleged natural and mind-independent relation between a statement and the objective world. A set of common sense descriptions or a scientific theory is true only if it is related to the world in a way describing the world as it really is.

The third element is the epistemic component: we have objective knowledge of the world as it is. Knowledge in the objective sense is independent of anybody's beliefs or anybody's claims of knowledge. Thus, the epistemic realist maintains that objective knowledge exists in the form of propositions and scientific theories. In other words, propositions and theories concerning the reality-in-itself are held to be true independently of whether we have proven, or might prove, them or not. As Karl Popper states this position: Objective knowledge is knowledge without a knowing subject (Popper, 1972, p. 109).

Since reality *an sich* for God would be one with his understanding of it, he does not, according to such a viewpoint, need reliable methods to prove his possession of objective knowledge. The world-in-itself would be inseparable from God's knowledge of it, or reality *an sich* would at least be congruent with his conception of it. For God as an infinite mind would not be bound by a distinction between the subject and the object. But mortal human beings, in contrast, need reliable procedures to determine whether or not their mental representations are in accordance with reality *an sich*. Thus, the fourth element of realism is the methodological component: in the right circumstances ordinary people or scientists are able to provide warranted judgement about the truth of all kinds of beliefs regardless of whether they are about observable or unobservable entities or are formulated in terms of singular or universal sentences. This is due to the fact that some objective methods or procedures exist such that their application yields a true belief that something is the case if and only if it is the case. Beliefs about the external world, according to the methodological realist, are ascertainable by reliable means: nevertheless, there are procedures which, when followed, yield only good, and not certain, grounds to believe that something is the case. Such a procedure provides us with a rational method by showing that the appropriate statement is likely to be true or false.

In order to defend his position, the realist is bound to explain what kinds of fact make statements about the external world true. He must give us a metaphysical account of how the truth value of statements about ordinary things, about unobservable objects and about natural laws is procured. Furthermore, the realist must explain how we can have epistemic access to ordinary things, the realm of an unobservable reality, and universal truths. He must point out which truth-conducive procedures of inquiry are at our disposal for gaining such knowledge. He must also identify under which circumstances we can know that truth conditions are in fact fulfilled, and in general, what conditions have to be fulfilled for a meaningful use of the sentence in question. Indeed, the realist's position becomes precarious if his metaphysical analysis of the truth conditions means that scientific facts lie beyond the empirical domain.

Having laid out these various forms of realism, it must be emphasized that some philosophers see themselves as both realists and empiricists. This is true of Karl Popper and Hans Reichenbach to mention only a couple. At the same time others, such as Bas van Fraassen, call themselves empiricists and antirealists. Whether one prefers to call oneself a realist or an antirealist is more or less inconsequential, so long as one holds most of the realist's presuppositions as one's own. More important than such labels is it that a given view is characterized unequivocally and exhaustively. However, there seems to be a tendency among those empiricists who consider themselves as epistemic optimists that they believe in the existence of some methods that can provide us with a rational belief in the claims of science; methods, that is, which makes scientific statements more or less probable. On the other hand, epistemic pessimists focus on an assumption that there are no reliable procedures of inquiry yielding the truth of scientific theories.

The opposition to realism with regard to theoretical entities of the invisible world has traditionally been marked by the instrumentalist doctrine. It entertains the view that theoretical concepts are merely heuristic tools for organizing the scientist's observations. Instrumentalists take a nominalist stand on theoretical entities. Common names and natural kind terms of unobservable entities don't refer to anything in reality; hence statements about these entities should not be considered literally true. All concepts of unobservable things, events and properties are nothing but logical constructions from observables. Accordingly, the backbone of this view is that invisible things like forces, fields, atoms, molecules, genes, and viruses are not real, and that the names of these things proclaimed are merely a unifying designation of concrete experimental results. This contention leads to the claim that scientific theories containing sentences about such imperceptible things do not express proper knowledge; instead they are inference schemes which can be utilized for predictions of future experiences on the basis of past experiences.

Instrumentalism is an ontological position about theoretical entities closely associated with the application of empiricist or phenomenalist constraints on what can possibly exist. Only things with which we are directly acquainted can be said to exist by any justification. Embracing such strong epistemic requirements on ontology, instrumentalism can be regarded as a form of non-cognitivism about what we cannot directly perceive. Similar non-cognitivist views have been asserted within other areas of human cognition: discussions about the reality of tenses, moral values, causality, probability and possible worlds can in many cases be seen as a continual battle between realists and nominalists. The question is therefore whether the instrumentalist has better arguments against the existence of theoretical entities than those of the phenomenalists against the existence of ordinary physical objects.

The language of science is full of terms that refer to invisible entities and properties. One therefore seems to be ontologically committed to entities and properties that we cannot see; unless the instrumentalist can prove, for instance, that all sentences concerning them can be translated without loss of meaning into sentences of a language in which each and very term concerns visible objects. Few instrumentalists, other than operationalists, would argue that a given theoretical sentence has the same intension as any observation sentence, that the truth conditions for a sentence ‘X is F’ containing terms for an unobservable object X and a similarly unobservable property F are identical with the truth conditions of an appropriate observation sentence, or a set of sentences, ‘Y is O_1, O_2, O_3, O_4, $\ldots$, O_n’, which only contains the terms for an observational object Y and the observational properties Os. An instrumentalist does not have to argue that these two sentences necessarily have the same meaning.

Another option for the instrumentalist would be to say that he does not claim the synonymity of such sentences but merely considered them coextensive. One way to vindicate such a consideration is to do like Ramsey and substitute existentially bounded variables for predicates and names. He proved that all theoretical predicates of a theory, i.e., terms of unobservables, can be treated as existentially quantified variables to the effect that the axioms of the theory links the predicate variables to each other and a dictionary links them to observables (Ramsey, 1930/1990). The result is that all problematic predicates are eliminated but the structure and observational consequences remain. If the so-called Ramsey sentence is true, it tells us to what we are ontologically committed. Therefore, Ramsey-sentences have been used in the attempt to get rid of theoretical terms and replace them with observational terms. In fact this was not Ramsey’s own purpose. Rather, he used his method to define the observational terms of observational language in terms of the theoretical terms of theory.

The instrumentalist disapproval of the fact that the language of science presupposes the existence of unobservables in order to be true is only one of two questions about the ontology of unobservables the realist must deal with. It is simply not enough for the realist to prove that the language of observables cannot express all our scientific beliefs. The other question rises from the fact that the language of logic and mathematics, for instance, requires the existence of abstract entities to be true. In Peano arithmetic we are committed to holding that natural numbers exist; and in Zermelo-Fraenkel set theory we have the same obligation towards sets. So, as Rudolf Carnap once pointed out, whenever we adopt such linguistic frameworks we are ontologically committed to the reality of numbers, sets, propositions, and so on (Carnap, 1950). He argues that whenever we wish to talk about some kind of being, we must do so within a linguistic framework. Such a framework is constituted by 1) a set of concept definitions, 2) some principles for governing the syntax between these concepts, and 3) some principles for testing the truth values of statements within the framework. In case of a rational (as opposed to an empirical) framework, 2) and 3) are coextensive.

The commitment is internal with respect to the framework. Carnap, however, argues that no metaphysical question can be answered inside the framework; thus it cannot have a truth value and is as such meaningless. When we ask if something *really* is, we are asking a question that goes beyond the conventional criteria for establishing whether something is. In his terms it is an *external* question to which there can be given no real meaning because it concerns reality considered outside a linguistic framework.

The plausibility of Quine's famous dictum hinges on a similar dichotomy between internal and external commitments: To be is to be the value of a bound variable (Quine, 1969, p. 91, ff). Existence is what existential quantification expresses. Thus the ontological commitment of a given theory can be found by identifying the entities over which the quantification of the theory is made. And Putnam's internal realism rides on the same ticket: "'Objects' do not exist independently of conceptual schemes. We cut up the world into objects when we introduce one or another scheme of description. Since the objects and the signs are alike internal to the scheme of description, it is possible to say what matches what" (Putnam, 1981, p. 52).

The realist's commitment is much stronger: the reality of numbers, sets, and propositions is a question about what *really* exists independently of any linguistic framework. A similar external commitment holds for the scientific realist with respect to unobservables. Thus, he must be prepared to argue for the correctness of the assumption that atoms, quarks, fields, and so on, exist objectively regardless of our way of conceptualizing the world. The realist is forced to show that his beliefs in unobservables can be warranted in some other ways than just by appealing to a given linguistic framework.

For instance, classical mechanics relies on everyday concepts like solidity, motion, and position in the observational description of macroscopic objects. But the usually crude determination of these attributes was not entirely satisfactory with the recognition of the renaissance that they could be measured and therefore become objects of mathematics. They could be turned into quantities. From then on a precise determination of their magnitude would involve instruments. Rulers, clocks, and levers were the basic instruments, and thereby mechanics got a new set of observables which were instrument readings. Such pointer readings must be connected with mass, position, and velocity through operational rules: meter sticks gauge the scale of distances, clocks record the elapse of times, levers measure the weight of masses, and velocity is uniform distances covered by equal times.

Newton's mechanics ascribes unobservable properties to observable entities. The ascription can be done through those of their properties we can experience. Quantum mechanics, however, deals with theoretical objects which cannot be object of direct perception; hence none of their properties can be attributed to them on our visual acquaintance with any of their other properties. Nevertheless, William Craig (Craig, 1956) and Carl Hempel (Hempel, 1965, pp. 173-226) have shown with respect to any such theory which can be axiomatized that it is always logically possible to construct an equivalent theory which entirely leaves out theoretical terms and expressions and replaces them with observational terms and expressions. Thus, theoretical terms are construed as meaningless auxiliary marks that serve as inferential devices between observational statements. Indeed, it has severe costs to choose a theory without theoretical terms such as lack of explanatory power, simplicity, and heuristic fertility.

The realist seeks the ontological commitments of our best scientific theories. The view that the physical world consists of a natural, pre-given and pre-descriptive set of laws, entities, properties, and relations is usually called scientific realism. And, according to the realist, the aim of science is to give a literal and objective description of such a world, and its present success can be seen as a token of the performance of these efforts. He holds that science eventually secures more and more knowledge about the world as it is in itself, and hence knowledge about a world of invisible things and properties. Likewise, the realist position is very often identified with the thesis that the theories that at the present time are considered the best are closer to the truth than earlier ones, and that the central terms of our best current theories are genuinely referential. This means, of course, that the truth of theoretical sentences about invisible objects and attributes are not reducible to the truth of a finite set of sentences about empirically accessible things and properties. As a reason for his position, the realist will point out that only if modern scientific theories are regarded as approximately true can we explain their predicative success.

2 Scientific realism

The scientific realist feels committed to a world of unobservables. But what counts as imperceptible entities and properties? How many or how few of the scientific terms stand for observables? Apparently, it varies from one science to another which physical entities or quantities we consider as observables. In general, macroscopic objects and events can be seen by the naked eye, and their visual properties like size, shape, form, solidity, colours, position, and motion are what distinguish them from each other. Some of these visual properties are ignored in a certain intended description of the object, since they are treated as secondary and mind-dependent properties, or because experience tells us that they don't play any role in the description of the object and its kinematical or dynamical behaviour. In classical mechanics, for instance, an object's position, velocity, rotation, and acceleration are the intended properties which are immediately accessible to the senses. Its mass is also a property we sometimes experience directly as the solidity of matter and feel by the weight. All other mechanical entities and properties like force, momentum, and kinetic energy are not observables; however, they can all be specified in terms of observables: $F = ma$, $p = mv$, and $E = \frac{1}{2}mv^2$. Classical mechanics ascribes certain non-observable properties to a physical object on the basis of observable ones. But the realist would say that these unobservable properties are something over and above the various relationships between the observable properties.

In his defence of realism, Michael Devitt presents us with the following train of thought: A person p is ontologically committed to an object a (or a property F) in uttering assertively a sentence token S if a (or F) must exist to make S true. Though Devitt will not deny the validity of this semantic criterion, he believes that there is another, more basic criterion, according to which a person is so committed if, in asserting S, that person says that a, or an F, exists (Devitt, 1984/1991, sec. 4.6). The first criterion requires that we possess a semantic theory for S to tell us what must exist to make S true, before we can say anything about a person's commitments; whereas the second criterion merely presupposes that we understand S as speakers of a certain language to know what commitments a person has. If someone asserts 'The electron is an atomic particle', this sentence is not true unless there exists something to which 'electron' refers and to which 'atomic particle' applies. But, says Devitt, the commitment of this to electrons and to atomic particles is the same as the one following from the assertions 'the electron exists' and 'the atomic particle exists'.

Devitt's argument is, I think, correct as long as it is taken to establish that no semantic theory is needed to know what existence really means. The word 'exists' in a sentence like 'the electron exists' does not have a meaning different from the one it has when we claim that the electron must exist for the sentence to be true. Had there been any difference between its meaning in the object language and the meta-language, we could decide to replace the meaning in the object language with its meaning in the meta-language, or if not, we might be involved in an infinite regress. But the fact that there is no difference does leave us without an argument to the effect that our commitments are external to the linguistic framework. Moreover, if the Craig-Hempel thesis holds and any theoretical sentence can be proven to be coextensive with a set of observation sentences, the realist is deprived of a strong reason to claim that our ontological commitments are external to the theory. For if a theoretical sentence cannot express a fact which cannot be expressed by a certain appropriate set of observation statements, why should we be justified in our beliefs that unobservable entities and properties are real?

The realist likewise sees the success of science as a strong backing of his thesis that scientific theories are typically approximately true. This success is also taken as evidence for the contention that theoretical terms within our best theories refer to whatever they are supposed to refer to. Sometimes it is even said that realism is the only conceivable view which can explain why science has been so successful, because the prediction of observable phenomena would be a cosmic coincidence or a miracle if theoretical terms only have instrumental value (Smart (1963, p.

39) and Putnam (1978, pp. 18-19)). Without the realist's explanation it would be especially incomprehensible how new and unforeseen phenomena can be predicted by a theory. The discovery of the element hafnium succeeded its prediction on the basis of Bohr's reorganization of the periodic system according to physical features of the atoms. As a consequence of his relativistic theory of the electron, Dirac announced the existence of a positive electron before Anderson discovered it. As an explanation of the continuous spectrum from beta decays, Pauli suggested the existence of an escort particle, the neutrino, which was not directly confirmed until many years later. The exchange of virtual mesons in a nuclear field was an essential part of Hideki Yukawa's theory of the strong nuclear force before these particles were discovered about ten years later. The W bosons and the neutral Z meson were first tracked down after they had for a while figured in Steven Weinberg and Abdus Salam's theory about the amalgamation of the weak and the electromagnetic force. All such examples make it highly unlikely, the realist contends, that theoretical terms making these predictions possible are not standing for entities other than those phenomena which can be observed.

The realist, however, also adduces other arguments for his thesis that theoretical terms refer to something real and we therefore are ontologically committed to imperceptible entities in a strong external sense. In searching for a systematization of his experience with the purpose of explanation and prediction, the scientist needs to operate with hypothetical entities that are not directly observable. As long as the scientist confines his effort to observable entities, the realist argues, he is merely able to formulate empirical generalizations. But, generally, the scientist is not content with the amount of integration which empirical generalizations alone furnish him. What he wants is a further integration of laws that bases itself on a few scientific principles, something that requires a further unification and development of concepts covering a broader domain of experience. The way to pass beyond the empirical generalizations must therefore be accomplished by introducing more general concepts not corresponding to anything observable. And, says the realist, the scientist eventually gets a better and better grasp of the world through his acquaintance with these principles, as he becomes able to expose the laws or mechanisms underlying the phenomena.

But how can this be an argument for the reality of unobservables or invisible entities? What the realist argues is that when the scientist aims at making an integration of concepts, he thereby justifies the ontological commitments entailed by our scientific theories. For the scientist seeks such unification only partly because of pragmatic reasons; that is, he wants to work with as few conceptual tools as possible. Rather the scientist believes that our concepts reflect something in the world. So if he can manage to narrow down the general concepts in his description of a certain domain to a very small number, he has reason to believe that that part of nature has been described in its most basic form. The realist's line of thought is that whenever science is capable of describing the world with all its difference and complexity, given very few concepts, it is most likely to be true because these concepts have dissolved the complexity into its most simple constituents.

This argument, however, suffers from two serious shortcomings. The first one is due to the fact that the conclusion is not consistent with the history of science. Many discharged theories, once used to explain an entire domain of experience in virtue of few general concepts, are not taken seriously anymore. Think, for instance, of the Aristotle's theory of motion. At its time it seemed to give a coherent account of our everyday experience of motions based on a few simple concepts. Vertical movement was considered dependent on the gravity of the body; dense things like rocks and water went downwards, more ephemeral things like air, vapour, and fire, upwards. Horizontal movement of a wagon, a stone, or an arrow required the presence of a moving force in the form of oxen, horses, or man power. All other motions could be described as a combination of these two principles. Likewise, the ancient idea of the world as being built up of the four basic elements, earth, water, air, and fire, contains much fewer elements than any contemporary theory. It is therefore doubtful, at least, that we today should have reached the right categories once and for all, just because we have been able to isolate a few concepts for explanatory purposes. The argument only shows that we always feel internally committed to those entities and properties which our currently best theories presume – it cannot prove that we are externally committed to such things.

The second objection is even more fatal to the realist's argument. For how can we be so certain that a scientific theory with fewer concepts is more likely to be true than one with more concepts? There are really no metaphysical grounds for believing that the world should consist of only few basic entities instead of multiple such. Similarly, nothing proves that these entities have fewer properties rather than more. Even if we grant the realist the existence of such proofs, it is impossible to see how that could help him to establish his belief that there are just those entities or properties which a certain scientific theory prescribes. For such a theory may turn out to be too simplistic in its assumptions about the basic number of entities or properties constituting its domain. Theories can start out by postulating very few entities and properties, and eventually have to go through a lot of conceptual extensions in order to cope with more and more experimental evidence for further entities or properties. Clearly, we do not particularly want a theory that posits superfluous entities or properties. But rejecting superfluousness is not the same as embracing simplicity. In my view, the ideal of simplicity is overrated, both when it comes to the number of entities and properties and to the structure of natural laws. Realists have nothing to gain from pursuing such an ideal.

In addition to the arguments discussed above, further reasons have been advanced in the support of the realist claim of real counterparts. Closely related to the latter argument is the question of abduction or inference to the best explanation. Against the instrumentalist it is said about scientific theories operating with unobservable structures and mechanics: because only some of them can explain all relevant facts in a coherent and convincing way, we have grounds to assume that those theories which are able to do so tell us how the world really is, or at least how it approximately is. However, we have to distinguish between at least two kinds of claims which may motivate the embracement of the inference to the best explanation. On the one hand, the realist may hold that the inference to the best explanation leads us to the objective laws of nature, and in such a case he could be called a realist concerning scientific theories; on the other hand, he may just urge the idea that the inference shows what is the most likely entity causing the effect, and in that case he could be said to be a realist concerning entities.

Abduction as well as induction plays an important role in formulating appropriate theoretical laws of science. But the realist will have a hard time if he wants to defend the view that inference to the best explanation is guidance to truth. Historically, this inference has fallen far behind the production of infallible knowledge, and we have little basis for believing that the situation will change in the future. What is considered to be the best explanation at any given time is whatever theory or assumption that seems to cover all chosen phenomena in the most satisfactory way. For more than a thousand years the Aristotelian theory of motion was the best explanation on the market. Then followed the impetus theory, which again was succeeded by the Galilean theory, the Cartesian theory, and by the Newtonian theory of motion – all of which were considered as the most convincing and adequate explanation of motion for a certain period of time. In the beginning of our century, Einstein provided the latest suggestion.

The realist may attempt to be modest, saying that the abductive inference only provides us with good reasons for an explanation more likely to be true. One may wonder, however, how to establish such a likelihood other than by saying that the theory is in agreement with all phenomena considered to be relevant at a given time. A correlation test, for instance, provides us with a measure of how good the correspondence is between the observed values and the expected values a given hypothesis predicts. Thus, if the measure of the likelihood is nothing but this external virtue, the realist must face the serious question of empirical underdetermination of theories. Usually, though, the realist will trade on internal virtues of a theory, like simplicity and coherence, as what characterizes the best explanation. But how can such internal virtues establish that the unobservables are real regardless of the conceptual framework?

To repeat: simplicity will not do the job. But perhaps coherence might? It could be argued that the idea of a world-in-itself is associated with the conception of everything being connected with everything else, and therefore somehow related to the idea that a hypothesis capable of explaining the facts is better if it agrees with other hypotheses than if it doesn't agree with any. At face value there is, however, a problem with such an argument. For the realist, a true hypothesis may or may not adhere with most other assumptions considered to be true. When the view of the truth-values of these other hypotheses eventually has changed, the hypothesis might be in agreement with the majority of commonly accepted assumptions. A good example of something like this would be the history of the heliocentric theory of Aristarchus of Samos. But the realist can avoid this problem by arguing that a claim is not scientifically interesting, even if it is true, before we have independent warrant for believing it. And he could continue by saying that so long as the hypothesis is not coherently connected with other commonly accepted assumptions about the world, it is not independently justified as true.

Also, the realist could emphasize that a hypothesis does not only have to agree with other reliable hypotheses to be better than its alternatives. It also has to agree with certain ontological principles forming the arrangement of the world, one of which I once named the principle of the unities of time, space, and cause after the classical drama (for instance Faye, 2002, p. 93). For instance, the realist may argue that an explanation has an a priori probability of being true if it accounts for a certain phenomenon in terms of other phenomena which are spatially and temporally connected with the phenomenon under discussion, all of which fit into the same ontic scheme of categories that can possibly enter into a causal relation. Nobody, to put it vividly, would dream of explaining today's hole in the ozone layer over Antarctica by the assassination of crown prince Franz Ferdinand in Sarajevo eighty years ago, because we regard such an explanation as entirely irrelevant. And the reason for this claim of irrelevancy is that the explanation suggested does not respect the unities of time, space, and action. Still, the realist must supply arguments that establish the validity of such a principle and which therefore show that coherence with this principle is necessary for an objective description.

The other way of looking at the inference to the best explanation is to say that it leads us to those entities which are causally responsible for the observed phenomena to be explained. By assuming that the existence of unobservable entities is causally responsible for what we can observe in the laboratory, realism yields the best explanation of why these physical phenomena are stable and occur in a regular way. They don't pop up by mere chance but are caused by underlying entities. A theory that explains different phenomena according to a common cause is also better than one which explains the same phenomena according to various independent causes. For example, as Wesley Salmon has pointed out, the determination of Avogadro's number, i.e., the number of molecules in a mole of any substance, was the decisive achievement in convincing the scientific community of the reality of atoms and molecules. What is crucial is not so much the fact that Jean Perrin succeeded in achieving a precise experimental value of Avogadro's number as the fact that within a few years, he and others reached the same number based on several independent methods and carried out on a variety of phenomena. Among those phenomena were Brownian movement, alpha decay, X-ray diffraction, black body radiation, and electrochemistry. Thus, ruling out the question of a striking coincidence, this remarkable agreement among the results of experiments, which seem to be quite independent of one another, can be taken as strong evidence of the hypothesis that behind the different phenomena there is something common causing their appearances (Salmon, 1984, pp. 214-227). Nevertheless, the history of science also seems, once again, to teach us another and different lesson. As long as the discussion is kept on the empirical level, there are historical cases where theories were regarded as the most prolific explanations available, but where the explanatory success wasn't enough to establish the reality of the entities proposed. The theories of phlogiston and caloric are just two overriding examples. Apart from this fact, the antirealist is always in a position to argue, as Bas van Fraassen does, that a case of the type Salmon mentions merely shows that our best theories are empirically adequate (van Fraassen, 1980, ch. 1). Such a case does not by itself establish philosophically that our theories of molecules have to be true, or that molecules are real.

What is wrong with the realist's argument for the inference to the best explanation is not that no such inferences are used in science. But it fails to prove that we are ontologically committed to those entities or laws of nature which are made subject of our best explanation. The argument works only in favour of the realist's point of view, after he has proven that we do have ontological commitments to the entities and properties postulated by those theories that are empirically adequate.

3 The success argument

I propose that we distinguish between two sorts of scientific success: One kind being related to science's ability to conceptualize the so-called unobservable world in terms of categories and principles in a rigorous fashion, which in turn allows us to make substantially correct prediction of numerous observable phenomena. Let us call this *theoretical or predictive success*. The other being related to our technological conquests of the unobservable world and our ability to manipulate it to create new effects. This kind can be called *practical or manipulative success*.

Theoretical success amounts to the fact that science until now has worked, that scientific theories have passed many empirical tests without being refuted, and that they yield coherent explanations of many otherwise unconnected phenomena. It therefore seems justified, the argument continues, to consider those unobservable entities postulated by a theory as real if they can be used to account for a large number of observable phenomena. So because a concept like 'field' enters into a theoretical explanation of gravitational and electromagnetic phenomena, the realist believes that we have sufficient reasons to assume that this concept stands for an objective feature of reality. If, on the other hand, the unobservable entity in question has been introduced only for the benefit of a certain and rather specific calculation, it is not reasonable to assume that the term by which it is introduced refers to anything in the world, unless, of course, it helps the scientist to predict a new phenomenon.

The practical success makes science successful in virtue of our ability to construct an advanced technology on the basis of the insight in nature we gain from applying scientific theories on practical problems. However, even though science by and large can be said to be successful in both of the above senses, the fact that science can be ascribed theoretical success hardly counts as a strong argument for scientific realism.[1] Theoretical success should merely be taken as evidence that current scientific theories are what they are supposed to be, namely, empirical adequate. For explanatory success depends here entirely on predictive success. It seems as if a causal theory cannot have explanatory success without having predictive success. But does it hold the other way around?

Sometimes it is claimed that predictive success does not imply explanatory success as, for instance, in the case of quantum mechanics. It is held to be an example of a theory with very little explanatory power but with a lot of predictive force. Obviously, in this case the denial of the converse implication happens to rest on premises that are very sensitive to what kind of notion of explanation one subscribes to. However, with respect to the present discussion of what can be inferred from the success of scientific theories, it is not useful to make a distinction between predictive and explanatory success.

In the history of science, and even in science today, there are many examples that theories may be used to predict future phenomena, theories which are either not true, or whose central terms do not refer to something real – e.g., the Ptolemaic system for the motion of the planets and Newton's theory of gravitation. In principle the Ptolemaic theory could still be used for predicting the course of the planets on the vault of heaven, in spite of the fact that nobody any longer believes that the planets are satellites moving around the earth. Such predictions have become even more achievable today because of the calculative power of current computers. Nevertheless, nothing in reality corresponds to 'epicycles' and 'geocentric orbits', the most central terms within the theory. Analogously, the world cannot be as we are told by Newton's theory of gravitation, if Einstein's general theory of relativity gives us the correct description on a grand scale. The central term of the theory, 'gravitational force', does not refer to something in reality; instead it has been replaced with geodic curves in spacetime. But the Newtonian theory is indispensable

[1] Several philosophers share the view that theoretical success implies scientific realism. See, for instance, Boyd (1973, 1985, 1990); Newton-Smith (1978, 1981); Niiniluoto (1977).

for calculations of many astronomical and technological problems in connection with space research, tidal movements, etc.

The conclusion is therefore that predicative success implies neither truth nor referential success. Scientific realism cannot make capital out of the fact that science has strong predicative success. What predicative success proves is that the world works as if there were the entities. Rather, the fact that some theories have useful predicative power without being true or having referential success can be seen as a confirmation of certain version of antirealism.

But what about the converse implication: Do truth and referential success imply predicative success? As Larry Laudan brings to light, scientific theories may be genuinely referential without being successful (Laudan, 1982, p. 223). The examples he mentions are Dalton's theory of atoms, the Proutian theory that the atoms of heavy elements are made up of hydrogen atoms, and Bohr's early theory of the electron. All of these were apparently genuinely referring theories, in spite of fact that they made a lot of flawed claims about atoms and their constituents, and hence in the end turned out to be unsuccessful. Laudan also rejects a possible realist retreat, according to which it is said that a theory whose central terms refer will usually be successful. He does so because, as he says, it is always possible by the use of negation to generate 'indefinitely many unsuccessful theories, all of whose substantive terms are genuinely referring'. And he compares this logical point with the many unsuccessful theories of atoms which have been proposed during the two millennia of speculations about the nature of matter. If Laudan were correct, it would imply that the realist's argument at this point is badly damaged.

Nevertheless, I don't think that Laudan gives the realist sufficient benefit of the doubt. I believe that a realist with perfect justice may claim that various historical theories were not successful because some of their central terms did not designate anything. Some of them did, of course, since scientists had correctly identified those entities in question. But Laudan seems to imagine that the realist position involves only that substantive terms are referring. Against this, the realist could argue that the most important predicative terms should also have to be genuinely satisfied for a theory to be successful. For example, a sentence like 'Electrons move around the nucleus in stationary, but classical orbits' expresses one of the fundamental assumptions Bohr made. Here the realist could argue that the terms 'electron' and 'nucleus' refer, whereas predicates like 'move around in stationary but classical orbits' and 'have a determinate position and a determinate momentum' are not satisfied. And for this reason Bohr's theory was wrong: It ascribed the wrong attributes to the right entities. So what made some of the theories mentioned unsuccessful was in fact that some property terms of the theories failed to be satisfactory defined or turned out to be empty.

The above example also reveals how truth and reference are related for the realist. Usually, the truth of a theory is taken to imply the genuine reference of its theoretical terms, while genuine reference does not imply truth. A theory can only be true or approximately true if its terms have real counterparts. In other words, whereas truth is, even according to realists, assumed to be sufficient for successful reference, reference is merely supposed to be necessary for truth. This is not the place to take a more careful look at the realist notion of truth. But we still have to finish our discussion of whether scientific success is a parasite on genuine reference.

In addition to the putatively theoretical success of explanation and prediction, science is connected with practical and technical success. Maybe successful predictions are not a consequence of the fulfilment of the referential aspect of the theoretical terms employed, assuming that all what observation can provide us with are the genuine reference of the observational terms and hence empirically successful theories. Nevertheless, in science we are able to experiment with things which we cannot see with the naked eye; things which afterwards may, on the basis of the knowledge of their causal properties we gain from these experiments, be used in technical apparatuses and instruments. Thus, the realist could say that because we can manipulate with what we cannot see and bring about the observable effects we want to produce, this shows that the theoretical terms of both the causal description of the experiment and of the function of the involved apparatuses genuinely refer. It is an undeniable fact that we incessantly, with greater and greater success, create and construct new technologies by using such unobservable entities and processes as direct tools in the construction and operation of these technologies. But this fact would not be understandable unless our best current theories were genuinely referential. If we, for instance, were able to move around with individual genes in a cell, taking some out and putting some others in, thereby creating new organisms, it would be beyond any rational ground to suggest that genes are not real merely because we cannot see them.

As pointed out by Ian Hacking, the fact that electrons can be used as tools is the strongest evidence for scientific realism (Hacking, 1983, ch. 16). In his opinion it is not because one can make experiment with them that one is committed to believing in their existence. Nor is it because of electrons can be used to experiment on something else. What matters is that by understanding the causal properties of electrons we can use our knowledge to build devices in which the electrons will behave in a certain characteristic manner, whenever we want them to do so. Electrons can be prepared in such a way that they can be employed in the creation of phenomena we wish to investigate in some other domain of nature.

For the realist this amounts to holding that practical success implies referential success, although the converse entailment is not true; theoretical terms may indeed have reference without the referent being an entity that can be used technologically. The basic premise is that you may see something which doesn't exist, and wrongly believe things are real which you cannot see; but you can never manipulate anything which isn't there. And even less can you manipulate an entity to cause an effect unless it exists. The realist's conclusion, therefore, is that a theory of knowledge which confines knowledge to what can be seen *ad oculus* is not very convincing. Our power to manipulate unobservable things justifies the assumption that we finally have knowledge of the physical world as it exists in virtue of itself.

A fine example illustrating some of these points is the discovery of Hafnium.[2] The periodic system of the elements was not established until around 1870. When this happened, it was done only on the basis of the *chemical features* of the elements, and most chemists regarded it as a purely empirical classification of the elements. In 1897 J.J. Thompson suggested a connection between atomic structure and the periodic system; however, it was not until Niels Bohr's second theory of the atom that anybody was able to give a physically satisfactory account of all the elements from hydrogen to uranium, including the transition groups and the rare earths. The theory was a result of a mixture of ill-defined general principles and empirically based concepts coupled with an exceptional physical intuition. Among the principles and theoretical concepts were the construction principle (Aufbauprinzip), the correspondence principle, penetrating orbits, and symmetry concepts. On the empirical side was chemical evidence in the form of ionic colours, magnetic properties, ionization potentials, atomic volumes, polarizability, and physical evidence in the form of optical spectra. Relying on these data and forming principles, Bohr gave a physical description of the atomic structure of the various elements and of how the electrons build up in shells from one element to the next. This description was able to reproduce many of the characteristics of the old periodic system.

After the formulation of Bohr's theory it was soon strongly supported by its ability to incorporate evidence from X-ray spectroscopy made by Dirk Coster. This evidence was in agreement with the predictions that included the right number of curves for the absorption edges, indicating the possible configuration based on levels of three quantum numbers; the curves of absorption edges showed that the building up of electrons started out roughly where it was expected: and finally the curves almost visualized those parts of the periodic system in which the building up occurs at the intermediate, but still incomplete level. Likewise the theory predicted new results for the optical spectra of the elements which were successfully confirmed by Paschen and Fowler.

Nevertheless, Bohr's theory was overthrown a few years later, partly because J.D. Main Smith and E.C. Stoker changed it in order to cope with the structure and the existence of simple chemical compounds, and partly because Wolfgang Pauli could support their changes by his introduction of the exclusion principle as an

[2] My knowledge about the discovery of Hafnium rests entirely on an excellent study by Kragh (1979) and Kragh (1980).

explanation of the electron distribution in a single atom. In spite of that, Bohr's theory still had one big victory to claim. While he was working on his model, the element with atomic number 72 had not been satisfactorily identified. It was generally believed to be an element that belonged to the rare earths, and chemists were looking for it in ytterbium minerals. In 1911, Urbain claimed to have isolated this new element by the method of fractionations. He called it celtium. Eleven years later Urbain, together with the X-ray spectroscopist Dauvillier, announced that, based on a few X-ray lines, they finally had identified element 72 in agreement with Urbain's earlier chemical discovery. If, however, this claim had been correct, it would have been fatal for Bohr's theory, according to which element 72 should be considered to be a homologue of zirconium, and therefore have no chemical similarities with the rare earths as celtium was supposed to. Knowing this and unhappy with the quality of Urbain's and Dauvillier's X-ray lines, Coster and G. Hevesy succeeded within half a year to find the new element, called hafnium, among zirconium minerals. They, too, used X-ray spectroscopy to track down the new element, and on the basis of two excellent lines Coster identified them as part of its L-spectrum.

So far as one focuses only on the predictive success of Bohr's theory, one could, as van Fraassen would do, argue that the theory merely provided us with an empirically adequate account of the correlations of the various optical spectra of the elements and of the various X-ray spectra, and a similar account of the mutual correlations between these two kinds of spectra.

4 Constructive empiricism

A theory of elements is empirically adequate if the world is observationally as if there are elements. Van Fraassen distinguishes between the acceptance of a scientific theory and the belief in its (partial) truth, claiming that the acceptance involves only the idea that the theory saves the phenomena, not that it is true (van Fraassen, 1980, p. 8 and 12). Nevertheless, the acceptance of a theory about *S* means to take all its claims literally, both claims about observable and unobservable entities. His idea is that by acceptance we commit ourselves to using the entire potential of the theory as if *S* exists in giving explanation and doing research. Still, we should be agnostic about the claims a theory makes about unobservable entities because they cannot be observed. Consequently, according to van Fraassen, the confirmation of Bohr's theory would not force us to embrace a belief of atoms as real. The theory was accepted for a while, simply because it was considered to be empirically adequate in virtue of yielding successful predictions.

But is it possible to account for the discovery of hafnium without believing that Bohr's theory of periodic system is true regarding the assumption of atoms?

In more general terms: is it possible to accept a theory without being externally committed to the theoretical entities it is a theory about? The fact that Coster and Hevesy were able to isolate and produce hafnium in quantities so large that everybody directly could see the stuff seems to justify a belief in atoms. As scientists eventually accepted the reorganization of the periodic system on physical ideas, they had ways to identify the different elements on the atomic level, which, I hold, at the same time established the referent of hafnium, even before this element emerged for their eyes. Elsewhere I have argued for a criterial theory of meaning according to which the evidential criteria for identifying each element is part of the meaning of the name of that natural kind (Faye, 2002, pp. 72–78). There is a causal connection between the use of the name and its bearer. The causal connection is determined by the criteria we have elected to use to identify the bearer of the name; in the present case the evidence was in the form of chemical data and particular lines in the optical spectra and in the X-ray spectra. These evidential criteria are satisfied by the bearer's sortal properties, and they enter into the definition of a particular name 'hafnium' and determine the reference of that name.

The mere fact, however, that Coster and Hevesey could manufacture a new visible element by extracting unperceivable atoms hidden inside zirconium minerals seems unintelligible if we only think of the periodic system as an empirically adequate classification. The last point can be stated even more dramatically. A couple of elements between hydrogen and uranium do not occur in nature as, for instance, technecium. It is a metallic element that can be obtained by bombarding molybdenum with deuterons or neutrons. Now, if the only thing you do is to change one visible element into another visible element by adding invisible things to it, are you not vindicated in a belief that these invisible things exist?

When micro-physical processes can be deliberately manipulated in a purposeful and constructive manner, do we not then have strong and justified reasons to assume that our belief in the existence of atoms, deuterons, and neutrons is true? It seems to be impossible to explain the success of our technological innovations, unless we were able to refer to microphysical entities and to tell a causal story about them. This we are able to do only because we understand their causal properties, and we therefore can use that knowledge in designing experiments and doing measurements. In general, technological success requires that beliefs about what we are doing have to be true, and these beliefs can only be true if we are capable of identifying the entities involved and have knowledge about their causal behaviour.

Explaining that the use of unobservables implies beliefs, and not merely acceptance, as van Fraassen suggests, Sam Mitchell has concocted a functional argument for why it has to be so (Mitchell, 1988). First he lays down a condition which should be acceptable for an empiricist like van Fraassen: only if somebody would act differently towards two kinds of entities does it make sense to argue that he or she harbours different kinds of epistemic attitudes towards these entities; that is, having a belief in one kind and being agnostic about the other. Then he points out that observables and unobservables play no discernible different role in the design of experiments or construction of apparatus. Van Fraassen must therefore either claim that we should be agnostic about observables too, or that we should believe in unobservables too. But since van Fraassen seeks to found our attitudes toward unobservables on our justification for accepting them (namely that claims about them are part of an empirically adequate theory), then the justification for believing in the observables of the theory should be sufficient for believing in the unobservables of the theory. In my opinion, however, there are no obvious epistemic grounds on which to draw a demarcation between observable or unobservable entities.[3]

The criterial theory of meaning on which the causal relationship between the name and the bearer of the name is a result of identifying criteria allows the change of these criteria. The use of a natural kind term is always open to revision because the criteria are fallible. Whenever science discovers that what is regarded as identifying criteria does not refer to sortal properties, we may skip some of these criteria and replace them with new ones, or we may enlarge the number of remaining criteria, or in the worst case scenario, we may give up the idea that a certain set of criteria establish a reference to a genuine entity as it happened with caloric, phlogiston, etc.

5 Structural realism

No doubt, the scientific realist has a strong case if he refers to the technological spin-off from science as something that is sufficient to explain the referential success of scientific theories. The practical success of science supports the external commitment of the language of science. Notice, furthermore, the difference at this point between theoretical success and practical success: it is only the latter which is sufficient for referential success, whereas only the former is necessary for referential success. Technological progress is a result of our power to act and intervene into physical processes. It shows that there is an objective reality which we cannot immediately see with our unaided eyes but which we have cognitive access to through instrumental observations. But, taking this for granted, it still remains to be proved that this kind of progress could not be explained on the assumption that the manipulated reality always exists as a conceptually grasped set of entities, properties and relations, and that these might perhaps be described in another way if the cognitive abilities of human beings had been different.

The kind of realism we have opposed takes the present scientific theories to be true or approximately true about the nature of things. Due to the optimistic no-

[3] See, for instance, (Faye, 2000).

miracle argument it holds that only true theories can explain the success of science. Laudan has, in contrast, introduced the pessimistic meta-induction argument: the existence of theory-change in the past seems to supply good inductive grounds for holding that presently accepted theories sooner or later will be replaced by new theories. Therefore predictive success does trade on neither truth nor reference. The physical content of a theory permits it to be true or false, but then if a theory eventually is overturned by a new one, truth cannot be what explains the empirical success of a theory. In the attempt to stay clear of this dilemma, some realists argue instead that theories have empirical success because of the structure of mathematical formulation of a theory. This view, which John Worrall attributes to Poincaré, but which he was first to explicate, is called structural or syntactic realism (Worrall, 1989, p. 112). This form of realism, he argues, can account for the existence of no miracles and meets Laudan's objection that scientific realism is unable to explain the transition from an older theory to a newer theory in which the latter is inconsistent with the former. Structural realism gives us the best of both worlds and still explains why succeeding theories have empirical success.

Structural realism is not a full-blown realism. The idea is that science may completely misidentify the nature of things as they are described by the metaphysical and physical content of our best theories but still attribute the right mathematical structure. Worrall says, "The rule on the history of physics seems to be that, whenever a theory replaces a predecessor, which has however itself enjoyed genuine predictive success, the 'correspondence principle' applies" (Worrall, 1989, p. 120). This requires retention of structure across the change of theory in the sense that the mathematical equations of the old theory reappear as limiting cases of the mathematical equation of the new theory. Worrall's historical case is the transition from Fresnel's to Maxwell's theory of light. Fresnel's theory made correct predictions because it accurately identified certain relation between optical phenomena which depend upon something or other undergoing periodic change at right angles to the light. But what more specifically is a structural realist a realist about?

It cannot be that a realist interpretation of the meaning of scientific theories yields the understanding of the physical content of the laws of nature. In his discussion of this problem James Ladyman points out that structural realism may take the form of two alternative positions: an epistemological refinement and a metaphysical approach (Ladyman, 1998, p. 410). The epistemic structural realism holds that there are epistemic constraints on what we can know about the world. We are justified in believing that we possess objective knowledge if there happens to be a mathematical continuity across theory change and revolutions. This idea requires a clear-cut distinction between the structure and the content of our theories; that is, a distinction between the mathematical equations and the theoretical interpretation of the formalism.

It is possible to find some support for this view in Bohr's methodology of quantum mechanics. Bohr introduced the principle of correspondence, and no other physicist has made such an explicit use of the correspondence principle as a guiding principle in the formation of a new theory. Bohr realized that according to his theory of the hydrogen atom, the frequencies of radiation due to the electron's transition between stationary states with large quantum numbers, i.e. states far from the ground state, coincide approximately with the results of classical electrodynamics for a free electron. But his own model of the atom eventually failed to predict some of the spectroscopic phenomena which were observed in the years to come, and in the beginning of the 1920's it was quite obvious to Bohr and other leading physicists that they still had to look for the final theory. Hence, in the search for a consistent mathematical formalism that could predict all observations, it became a methodological requirement to Bohr that any further theory of the atom should predict values in domains of large quantum numbers that should be a close approximation to the values of classical physics. The correspondence rule was a heuristic principle meant to make sure that in areas where the influence of Planck's constant could be neglected, the numerical values predicted by such a theory should be the same as if they were predicted by classical radiation theory.

The correspondence rule was an important methodological principle. In the beginning it had a clear technical meaning to Bohr. It should guarantee that calculations based on the mathematical formalism of classical electrodynamics gave the same result as a new mathematical formalism in the limit. The way for the correspondence principle to secure such a result was to connect the frequencies of radiation on an atomic spectrum with the Fourier components of the motion of an electron in orbit and then "compare the radiation emitted during the transition between two stationary states with the radiation which would be emitted by a harmonically oscillating electron on the basis of electrodynamics" (Bohr, 1920/1976, p. 51). So Bohr considered quantum mechanics as a mathematical generalization of classical mechanics in which structural elements are preserved. Matrix mechanics fulfilled the promise of the correspondence principle in its retention of the forms of classical equations (Bohr, 1925/1984, p. 852). Accordingly, we can explain the predicative success of classical physics if we take into account that it agrees with quantum mechanics in the domain where the quantum of action did not play any significant role.

In contrast to modern structural realists, however, Bohr realized at the time he became involved in the interpretation of quantum mechanics that it did not suffice to preserve some structural features in order to get to the meaning of quantum mechanics. The formalism cannot be understood unless we continue to use classical concepts in describing the experimental result and we therefore have to apply these while interpreting the mathematical formalism[4]. I think Bohr was right. It is obvious, I believe, that it makes no sense to compare the numerical values of the theory of atoms with those of classical physics unless the meaning of the physical terms in both theories is somehow commensurable. So in Bohr's opinion the use of the correspondence principle in developing the new quantum mechanics substantiated the metaphysical idea that classical concepts, like position, momentum, and energy, are indispensable for our understanding of physical reality, and only when classical phenomena and quantum phenomena are described in terms of the same classical concepts does it make sense to compare the predictive results of different mathematical formalisms. I therefore take the example to show that the structural realists' attempt to draw an interesting philosophical distinction between structure and content, i.e., between formalism and interpretation is futile. For as long as Worrall's structural realism focuses on mathematical structure as separated from interpretation, it is unable to explain the predicative success of theories. To explain predicative success requires attribution of some substantive properties to the phenomena in question.

Ladyman also rejects the epistemological form of structural realism. It does not represent any advantage over traditional scientific realism. His objection concentrates on two possible understandings. One way is to look at a theory as a Ramsey structure in the sense that a Ramsey-sentence for the theory replaces the conjunction of all theoretical constants with distinct variables bound by existential quantifiers. The result is that theoretical terms are eliminated but that the observational consequences are being preserved. It is a mistake, however, to think that the theoretical terms are entirely eliminated. They are still being referred to, not directly with theoretical terms, but indirectly via their Ramsey descriptions whose direct referents are known by acquaintance. The idea is here that the world consists of unobservable entities between which observable properties and relations obtain. Thus the relations form the structure of the world, the structure itself is the abstract form of a set of relations that hold between these entities, and the relations are those which can be known. The problem with this understanding is, as Demopolous and Friedman have pointed out, that any structure of a set of relations can obtain from any (sufficiently large) collection of objects. But if that is the case, a given structure does not pick out a unique set of relations of the world. Therefore we should reject a Ramseyian understanding of the structure of a theory.[5]

Another understanding is proposed by Stathis Psillos, a reading which makes structural realism indistinguishable from traditional realism (Psillos, 1995, 1996). He argues that Worrall's mathematical continuity is not sufficient to answer the

[4] A preliminary attempt along these lines can be found in (Giere, 1988, 1999). For a criticism of his semantic view on theories, see (Faye, 2006).

[5] See (Newman, 2004) for a criticism of Ramsey sentence realism posed by Cruse and Papineau (2002).

pessimistic meta-induction; we need a positive argument which connects mathematical formalism as being responsible for the predictive success, an argument which shows that mathematical formalism represents the structure of the world. He also doubts that it is possible to discriminate between our ability to know the structure and our ability to know the nature of the world. Instead he thinks that structure and nature are inseparable; properties are defined by laws in which they feature, and the nature of something consists in its basic properties and their relation as they are structurally described in mathematical equations.

Ladyman advocates an ontic or metaphysical version of structural realism because only this can explain ontological discontinuity. The ontological commitment of structural realism is more than to the empirical content of a theory but less than to the full ontology of scientific realism. He also thinks that the ontic approach to mathematical structures fares well with the semantic or model theoretic view on theories because "theories are to be thought of as presenting structures or models that may be used to represent systems, rather than as partially-interpreted axiomatic systems" (Ladyman, 1998, p. 416). The predictive success of science, such as star light being bent near the Sun as predicted by general relativity, is possible to understand if we assume that the most abstract mathematical structures go beyond a correct description of actual phenomena and represent modal relations between them. He opts for an elaboration of structural realism that takes "structure to be primitive and ontologically subsistent" (Ladyman, 1998, p. 420). He then draws attention to Weyl's view on objectivity according to which the status of objectivity can be bestowed only on relations that are invariant under particular transformations. So ontic structural realism takes structures and relations to be real rather than objects and properties.

Some philosophers have raised objections to the ontic version of structural realism, but I do not have room for presenting these in any detail.[6] My own disagreement rests on the following considerations: First, the semantic view on theories is not necessarily a benefit for the structural interpretation. Not all proponents of the semantic theory of theories consider themselves realists. Bas van Fraassen is one example. Moreover, the semantic view on theories is beset with some of the same problems as structural realism. Both rely on assumptions which are difficult to bring to term. On the one hand, the immediate interpretation of a theory is taken to be a model of abstract objects; and on the other hand a theory consists of a set of descriptive sentences, each of which has a certain truth value.[7] According to an ontic structural realist who focuses on structure rather than content, theo-

[6] See, for instance, Pooley (2005): "The main thesis of this paper is that, whatever the interpretative difficulties of generally covariant spacetime physics are, they do not support or suggest structural realism." (Pooley, 2005, p. 2).

[7] Cf. (Faye, 2006) for further criticism of the semantic view on theories. See also (Faye, 2002, ch. 8).

ries represent concrete structures, which means that a scientific theory is true or false with respect to some concrete relations and structures in nature. But how can we assign a truth value to a mathematical equation in virtue of actually existing structures if we understand its meaning in virtue of knowledge of abstract objects and relations? The structure of a theory does not correspond directly to some real structure but to the structure of some models which constitute the interpretation of the theory; i.e., a mathematical expression is structurally coherent with its models, and one of them may then be isomorphic with a real structure. It remains a puzzle to me how we can understand a theory's structure by having access to the abstract structure of the models.

Second, realism in terms of metaphysical structuralism seems to represent a naïve view on the relationship between mathematics and reality familiar from Wittgenstein's old picture theory of language in *Tractatus*. The metaphysical structuralist sees mathematics first and foremost as a means to representing the world in thought. The function of mathematical formulas is to represent how the world is structured. This is possible only in so far as the meaning of a mathematical equation is established in virtue of a corresponding structure which, if it is realized, makes the mathematical formula true. As Wittgenstein argued with respect to language, any combination of sentences consists of a relation of logical structures of atomic sentences, and these atomic sentences stand in a direct relation to the corresponding possible facts so that the sentences are isomorphic with the atomic states of affairs they picture. Similarly, a mathematical formula forms a structure itself, and this structure gets its meaning by saying that the world is structured in the same way as the formula in order for it to become true. In this sense the mathematical structures are logical pictures of possible real structures. The mathematical structure of theory mirrors or pictures the structure of factual relations. Thus our currently best scientific theories and reality exhibit a mutual isomorphism by having the same structural form.

Setting side the later Wittgenstein's criticism of the picture theory, there is, I think, an important difference between his attempts to grasp the function of language in terms of the atomic sentences that picture possible facts and the ontic structural realists' attempts to understand the function of scientific theories in terms of mathematical structures that are isomorphic with some possible factual structures. Wittgenstein's idea was combined with an idea that we have direct empirical access to the facts which were pictured by a language; say, the cup is on the table. But structural realists cannot have a similar empirical knowledge of the *modal* relations of the world, since these structures are ontologically independent of the entities that participate in them. The object of theories is mathematical structures, real counterparts to our mathematical equations, but we have no plausible way to get to know their existence by traditional empirical inquiry. All we can observe and manipulate are objects and their properties.

Third, it does not suffice for the structural realist to point to the ontological commitments of structures given to us by theories. The commitment to a certain structure is always internal to the mathematical framework. The structural realist needs to point to some external commitments. Again, I think that Bohr pointed to some fundamental problems concerning the mathematical structure of our current physical theories to the effect that no such external commitments subsist. In both quantum mechanics and relativity theory we meet complex numbers in the formulation of some of the basic questions such as the commutation rule and the four-interval invariant relation. He therefore rejects the idea that theories give a 'pictorial' representation of the world (Bohr, 1999, p. 86, 105). His reasons seem to be that mathematical structures, which appear as a result of the use of imaginary numbers, can never be real and thus be object of our experience because the existence of imaginary numbers is due to a mathematical abstraction from real numbers. This deprives us from having any external commitments with respect to the structure of such theories.

The final objection I briefly want to present is this. Scientific theories are in general empirically underdetermined. Theories may therefore be empirically equivalent without having the same content or structure. The mere fact that it is possible in principle to construct such theories that have different content and structure should make us suspicious of the ontological claims of structural realism. For if the same observable facts can be described satisfactorily by structurally different theories, we have no reason to argue that mathematical equations represent objective relations and therefore no objective grounds to prefer one particular formulation rather than another.

In my opinion, ontic structural realism relies on an indefensible position on the relationship between mathematically formulated theories and the world: There exists an isomorphic coherence between the mathematical structures, which exist independently of the world, and the real structure of the world as it exists independently of mathematics. This assumption makes sense only if both mathematics and the world are designed according to the same principle of reason that allows a "picture" or "translation" of the logical relations between the elements of the world into logical relations between mathematical elements. In this way, a universal logic functioning as a superior principle for both mathematics and the world guarantees epistemological objectivity. This is all fairly mystic. In contrast, I believe that a less speculative and more practicable approach to an understanding of mathematically formulated theories and their relations to the world does not go via syntax and formal semantics, but through a more cognitive approach to science which may involve ideas from cognitive semantics[8].

[8] A preliminary attempt along these lines can be found in (Giere, 1988, 1999). For a criticism of his semantic view on theories, see (Faye, 2006)

6 Conclusion

Invisible entities exist. We do not need scientific theories to be true or approximately true in order to discover the existence of invisible entities. Entities can be, and often are, discovered without scientists having any developed theory at their disposal. We are committed to their existence whenever we are able to interact with them in a constructive way. The truth of scientific theories is not needed because the relation between theory and entities are mediated by models. The entities such as planets, stones, pendulums, light, atoms, electrons, photons, and quarks are not, and will not be, the direct objects of any theory. I have elsewhere argued that fundamental laws, like Newton's laws, Maxwell's laws, and Schrödinger's equation, function as definitions by stating relations between set of quantities (Faye, 2005); see also (Faye, 2002, ch. 8). A theory consists of a vocabulary of certain idealized properties which are then defined as quantities in some mathematical equations. The equations interrelate quantitative terms by defining some of them in terms of the others. Not until a mathematical model is established, which is an abstract representation of some concrete objects, will these quantities become identified with the properties of specific entities. We can then use this abstract model to explain the behaviour of the corresponding physical entities. The upshot is that since past and present theories do not deal with concrete entities but only define idealized attributes, scientific theories may change without affecting our ontological commitment of the entities involved.

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