Did Perrin's experiments convert Poincaré to Scientific Realism?

Milena Ivanova

(forthcoming in *HoPoS: The Journal of the International Society for the History of Philosophy of Science*, volume 3, issue 1)

Abstract

In this paper I argue that Poincaré's acceptance of the atom does not indicate a shift from instrumentalism to scientific realism. I examine the implications of Poincaré's acceptance of the existence of the atom for our current understanding of his philosophy of science. Specifically, how can we understand Poincaré's acceptance of the atom in structural realist terms? I examine his 1912 paper carefully and suggest that it does not entail scientific realism in the sense of acceptance of the fundamental existence of atoms but rather, argues against fundamental entities. I argue that Poincaré's paper motivates a non-fundamentalist view about the world, and that this is compatible with his structuralism.

Keywords: Atomism; Fundamentalism; Henri Poincaré; Scientific Realism; Structural Realism

1. Introduction

In the current literature it is widely accepted that Poincaré advanced structural realism, which commits one to the structural claims of scientific theories and not the claims regarding unobservable entities. However, Poincaré's (1913)[1] paper, in which he accepts the reality of the atom, appears to go against his anti-realism regarding unobservable entities and thus challenges our current understanding of his philosophy as defending structural realism.

In this paper I examine whether Poincaré's acceptance of the atom indicates a shift from structural to scientific realism, which would accommodate his alleged commitment to unobservable entities. I explore why admitting the reality of the atom would seem to challenge Poincaré's structural realism but argue that Poincaré's argument is compatible with his Kantianism and structuralism. By looking at Poincaré's argument for the acceptance of the atom closely, I argue that it is not intended as a positive argument in defense of realism towards unobservable entities but is aimed against fundamentalism, a thesis according to which reality is composed of levels and there is a fundamental level on which the rest supervene. I examine the argument and suggest that it is an inductive argument against fundamentalism. I show that this argument is compatible with Poincaré's structural realism.

The structure of this paper is as follows. In section 2, I present structural realism, a view which, in the modern literature, is taken to originate in Poincaré's philosophy of science. Section 3 presents Poincaré's argument for the acceptance of the atom, developed in 1912, just after Perrin's experiments were announced. In section 4, I examine how this acceptance challenges a structural realist interpretation

[1] The paper was presented in 1912 before the French Society of Physics and published in Poincaré's (1913).

of Poincaré's philosophy, and how it could be seen as suggesting a shift towards scientific realism. In section 5, I concentrate on the argument for the acceptance of the atom and show that Poincaré did not only argue for the changing status of the atomic hypothesis but also against fundamentalism. In section 6, I explain why this argument is compatible with structural realism. Section 7 is the conclusion.

2. Poincaré's Structural Realism

In the modern literature, Poincaré's view about scientific theories has been revived by John Worrall (1989) and since known as 'structural realism'[2]. This view is motivated by two different problems with which Poincaré was concerned – how to account for the novel predictive success of scientific theories, and also for the constant failure of these theories to reveal the underlying nature of reality.[3] In a famous passage from *Science and Hypothesis*, Poincaré formulated the argument for the 'bankruptcy of science', known in the modern literature as the 'pessimistic meta-induction'. According to Poincaré:

> *The* ephemeral nature of scientific theories takes by surprise the man of the world. Their brief period of prosperity ended, he sees them abandoned one after another; he sees ruins piled upon ruins; he predicts that the theories in fashion to-day will in a short time succumb in their turn, and he concludes that they are absolutely in vain. This is what he calls the *bankruptcy of science*. (Poincaré 2001, 122)

The pessimistic meta-induction motivates anti-realism[4] about scientific theories. Following Duhem, who famously stated that the history of science is the grave yard of attempted explanations, and Poincaré's argument for the bankruptcy of science, Larry Laudan (1981) makes a meta-induction over failed past theories[5] to argue that we have inductive grounds to conclude that our theories, in their turn, will be abandoned. This argument motivates anti-realism about current scientific theories. But neither Poincaré, nor his contemporary, Pierre Duhem, were anti-realists about scientific theories. The reason is that the history of science also motivates scientific realism.

Both Duhem and Poincaré are struck by the ability of scientific theories to predict novel facts, that is, phenomena that the theories are not designed to save are nevertheless predicted by them. Duhem calls such theories 'prophets': "a theory that tells us the results of an experiment before it has occurred." (Duhem 1954, 27)[6] In

[2] The term 'structural realism' was first introduced by Grover Maxwell in his (1962), referring to the thesis developed by Bertrand Russell in *The Analysis of Matter* (1927). Structural realism, as a thesis motivated by the problem of theory change, was first introduced by Giedymin (1982) in the context of Poincaré's views on scientific theories and made widely known by Worrall (1989).

[3] Note that the argument from theory change is not the only argument Poincaré develops as a motivation for structural realism. Apart from his claim that only relational knowledge survives theory change, which is historically contingent, Poincaré also argues that theories themselves are systems of relations expressed by mathematical formalism (Poincaré 1902, 144-145) and also that the aim of science is to discover relations not the 'causes' or 'natures' of realities (Poincaré 1902, xxiv).

[4] For this argument Poincaré is often interpreted as instrumentalist or conventionalist. However, these readings do not take into consideration the positive arguments advocated by Poincaré, such as the no miracles argument and the argument for continuity in theory change.

[5] The examples Laudan mentions are many: crystalline spheres in astronomy, the caloric theory of heat, the vibratory theory of heat, the ether theory, the phlogiston theory, etc.

[6] Examples of empirically successful theories which managed to make novel predictions include Newtonian Mechanics' prediction of the existence of a hitherto unobserved planet, Neptune (the prediction was done independently by Le Verrier and Adams between 1845 and 1846 and the planet

articulating this argument further, Putnam suggests that "realism is that it is the only philosophy that does not make the success of science a miracle." (Putnam 1975, 73) This 'no miracles argument' suggests that no explanation of the success of scientific theories in predicting novel facts can be provided if we adopt anti-realism. In order to explain this success, we should believe in the (approximate) truth of our theories, therefore adopt scientific realism.

As already mentioned, Poincaré attempts to account for both arguments from the history of science. He argues that even though theories are abandoned, there is continuity at the level of mathematical equations in theory change. He suggests that science is cumulative and that the empirical success of old theories is preserved in the new theory. What is lost is the ontology of the theory – the theoretical entities associated with the interpretation of the equations. The mathematical equations nevertheless, survive theory change. This following passage from Poincaré is a defense of structural realism[7]:

> The ephemeral nature of scientific theories takes by surprise the man of the world. Their brief period of prosperity ended, he sees them abandoned one after another; he sees ruins piled upon ruins; he predicts that the theories in fashion today will in a short time succumb in their turn, and he concludes that they are absolutely in vain. This is what he calls the *bankruptcy of science.*
> His skepticism is superficial; he does not take into account the object of scientific theories and the part they play, or he would understand that the ruins may be still good for something. No theory seemed established on firmer ground than Fresnel's, which attributed light to the movements of the ether. Then if Maxwell's theory is today preferred, does that mean that Fresnel's work was in vain? No; for Fresnel's object was not to know whether there really is an ether, if it is or is not formed of atoms, if these atoms really move in this way or that; his object was to predict optical phenomena.
>
> […]
>
> It cannot be said that this is reducing physical theories to simple practical recipes; these equations express relations, and if the equations remain true, it is because the relations preserve their reality. They teach us now, as they did then, that there is such and such a relation between this thing and that; only the something which we then called motion, we now call electric current. But these are merely names of the images we substituted for the real objects which Nature will hide for ever from our eyes. The true relations between these real objects are the only reality we can attain (Poincaré 2001, 122)

---

was first observed by Galle in 1846), Mendeleev's periodic table of elements, which in 1870 predicted the existence and atomic properties of three unknown elements (Gallium, Scandium, Germanium), and Fresnel's wave theory of light predicted that a white spot would appear at the center of a shadow of an opaque disc.

[7] Duhem also argues that a 'natural classification', an empirically successful theory that makes novel predictions and is unified with other theories, "expresses profound and real relations among things." (Duhem 1954, 28)

Worrall (1989) argues that the above arguments given by Poincaré favour structural realism, which accounts for both the pessimistic meta-induction and the no miracles argument. The idea is that at the level of ontology we should be anti-realists and believe that the entities postulated by our current theories are probably going to be abandoned, as is the case with the caloric, the ether and phlogiston. But we can be realists at the level of structure, which is expressed in the mathematical equations that survive theory change.[8] Worrall argues, using the example discussed by Poincaré of the transition from Fresnel's elastic ether theory to Maxwell's theory of the electromagnetic field, that:

> There was an important element of continuity in the shift from Fresnel to Maxwell—and this was much more than a simple question of carrying over the successful empirical content into the new theory. At the same time it was rather less than a carrying over of the full theoretical content or full theoretical mechanisms (even in "approximate" form). … There was continuity or accumulation in the shift, but the continuity is one of form or structure, not of content. (Worrall 1989, 117)

According to structural realism science is cumulative; in theory change there are elements of the old theory that are retained in the new one. This preservation is structural, not ontological, and is expressed in the mathematical equations of empirically successful theories. In the transition from Fresnel's theory to Maxwell's theory of electromagnetism the equations of the former theory are completely preserved in the latter theory. These equations carry different interpretations: in Fresnel's theory light is a disturbance in the ether, in Maxwell's theory the disturbance is due to the nature of the electromagnetic field. Nevertheless, Worrall argues, "Fresnel's theory had correctly identified certain relations between optical phenomena, the equations of Fresnel's theory are directly and fully entailed by Maxwell's theory." (ibid, 159) It has been objected that the above example of theory change is not typical for theory change. Worrall, however, argues that more often in the history of science the equations of the old theory are limiting cases of the equations of the new theory. The structural continuity is shown by the general correspondence principle.

It is debatable whether Poincaré's philosophy can be characterised as 'realist', as Worrall's reading suggests. A premise of structural realism is the metaphysical claim that the world has a mind-independent structure which scientific theories discover. Poincaré does not seem to be committed to this claim. As Mary Domski (2000) argues, Worrall's characterisation of Poincaré is limited and does not preserve central arguments Poincaré develops in his epistemology, such as his neo-Kantianism and his conventionalism. Poincaré's conventionalism is rooted into his neo-Kantian understanding of geometry. Even though Poincaré argues that we make a conventional choice between geometries of constant curvature, and in that sense geometry is conventional and not synthetic a priori, geometry is nevertheless constructed from the concept of a group which pre-exists in our mind and is constitutive in the same sense

[8] Poincaré argues that the equations reveal the relations between 'real things', the 'things in themselves' while leaving their intrinsic 'natures' unaccessible to us. Worrall's also employs the Ramsey sentence approach to structural realism. By dividing the content of a theory into observational and theoretical and by replacing every theoretical term by existentially bound variables, the Ramsey sentence can eliminate direct reference to unobservable entities. It renders the first-order properties and relations of theoretical entities epistemically unaccessible, while the second order properties and relations are epistemically accessible.

the synthetic a priori is for Kant (Poincaré 2001, 59).[9] He also believes that arithmetic, a necessary presupposition for geometry, is synthetic a priori. As a consequence we can obtain knowledge of the relations only by employing a framework of constitutive principles that are imposed on the world by us. Thus, Poincaré's view could be better characterised as internal structural realism, a view which does not commit one to the metaphysical premise of scientific realism.

3. Poincaré's acceptance of the atom after Perrin's experiments

Before Jean Perrin's experiments, Poincaré regards the atomic hypothesis with the same hostility as Duhem, and also Ernst Mach and Wilhelm Ostwald, who argue against it on methodological and scientific grounds. Poincaré regards the atomic hypothesis as 'indifferent', meaning that it cannot be subjected to empirical test and can therefore be adopted at best as a fictional instrument but abandoned as soon as it fails to serve its purpose. According to Poincaré the atomic hypothesis belongs to the set of 'indifferent' hypotheses because even if the theory that adopts it is confirmed, we can in no way conclude that it is true. Before calculations are produced we can *either* adopt atomism, and believe that matter is composed of small particles, *or* contrary to atomism, suppose matter to be continuous. In each case, Poincaré argues, we are going to produce the same calculations.

Atomism is unappealing to Duhem, Mach and Ostwald because it explains observable phenomena in terms of unobservables. Duhem, for example, strongly disagrees with atomism on methodological grounds. He believes that the method followed by the proponents of atomism is not scientific but metaphysical, and as a consequence, by adopting atomism we are delaying the progress of science. Since our experience does not give us knowledge of the unobservable, searching for causes beyond the observable makes science become "subordinate to metaphysics." (Duhem 1954, 10) Duhem states that "these two questions—Does there exist a material reality distinct from sensible appearances? And What is the nature of this reality?—do not have their source in experimental method, which is acquainted only with sensible appearances and can discover nothing beyond them. The resolution of these questions transcends the methods used by physics; it is the object of metaphysics." (ibid)

Duhem and Poincaré's methodological objection to atomism is also expressed by Ostwald. As Peter Achinstein (2007) suggests, Ostwald's objections were scientific as well as philosophical. Ostwald disagrees with the reductionist approach of atomism because it reduced non-mechanical phenomena, such as heat, electricity and magnetism, to the motion of atoms which obey only mechanical laws. Most importantly, Ostwald disagrees with atomism on methodological grounds holding that the aim of science is not to discover 'essences' (i.e. the causes of the phenomena), but to coordinate measurable quantities; for this reason, atomism violates the aim of science.

While Ostwald and Poincaré changed their view regarding atomism after Thomson's and Perrin's experiments, which are regarded as decisive evidence in favour of atomism, Duhem never accepted the atomic hypothesis. The reason for this comes from the fact that he was not only a physicist and a philosopher, but also a chemist, involved in the development of an alternative scientific theory. Duhem was a proponent of the (then) empirically equivalent theory of energetics, which according to him, can account for the same phenomena without using metaphysical claims

[9] Poincaré's 'hierarchical' approach of different a priori, conventional and empirical sciences and their relationship and epistemic status is discussed in detail in Friedman (1999, 71-89).

regarding the nature of matter. Even after Perrin's experiments are known to him, he argues that:

> The school of the neo-atomism, the doctrines of which center on the concept of the electron, have taken up again with supreme confidence the method we refuse to follow. This school thinks its hypotheses attain at last the inner structure of matter, that they make us see the elements as if some extraordinary ultra-microscope were to enlarge them until they were made perceivable to us. (Duhem 1913, 238)

> Our own view, Energetics, does not proceed in this manner. The principles it embodies and from which it derives conclusions do not aspire at all to resolve the bodies we perceive or the motions we report into imperceivable bodies or hidden motions. Energetics claims to explain nothing. Energetics simply gives general rules of which the laws observed by the experimentalists are particular cases. (ibid., 233)

Unlike Duhem, Poincaré's disagreement with atomism does not stem from his advocacy of the theory of energetics; he accepts that atomism could serve as a useful hypothesis but stresses that we should not take it at face value. His skepticism about atomism stems from the methodological worry that hypotheses about unobservable entities are tested holistically, a fact that does not entail the confirmation of the atomic hypothesis in light of agreement of the theory with experiment:[10]

> If, then, experiment confirms his calculations, will he suppose that he has proved, for example, the real existence of atoms? […] These indifferent hypotheses are never dangerous provided their characters are not misunderstood. They might be useful either as artifices for calculation, or to assist our understanding by concrete images, to fix our ideas, as we say. (Poincaré 1902, 117)

Poincaré's objection to atomism stems from the impossibility of independently testing a hypothesis that makes claims about the unobservable reality. He does accept that these hypotheses might prove useful for making predictions but nevertheless believes that, given the holistic nature of confirmation, we cannot establish their truth.[11]

> The object of mathematical theories is not to reveal to us the real nature of things; that would be unreasonable claim. Their only object is to coordinate the physical laws with which physical experiments make us acquainted, the enunciation of which, without the aim of mathematics, would be unable to effect. Whether the ether exists or not matters little—let us leave that to the metaphysicians; what is essential for us is, that everything happens as if it existed, and that hypothesis is found suitable

[10] One could of course argue that this goes against Poincaré's defence of a non-holistic approach to epistemology. However the fact that he defends the role of constitutive principles, which he calls 'conventions in disguise', is a separate issue to the fact that he advocates a holistic approach to confirmation, at least in his discussions of the atomic hypothesis. The atomic hypothesis is indifferent, not constitutive, so it does not have the same epistemological status.

[11] Poincaré suggests that questions regarding the existence of unobservable entities, such as electrons or the ether, are "devoid of meaning." (Poincaré 1902, 125)

> for the explanation of phenomena. […] some day, no doubt, the ether will be thrown aside as useless. (ibid, 156)

To summarise, the reason for Poincaré's skepticism towards the atomic hypothesis is due to its dependence on unobservable entities, and impossibility of subjecting it to empirical test. However, Poincaré's view appears to change dramatically in his 1912 paper, where he accepts the existence of the atom. What Perrin had done in his experiments, which was quickly made known to Poincaré, was provide evidence for the existence of molecules and atoms based on thirteen distinct ways to calculate the precise value of Avogadro's number (the number of molecules contained in a mole of gas). Familiar with these results, Poincaré famously argues that:

> The former hypotheses of mechanics and atomic theory have of late assumed scientific consistence to cease appearing to us as a hypothesis. The atoms are no longer a convenient fiction; it seems so to speak, that we can see them since we know how to count them. (Poincaré 1913, 89)

> The brilliant determinations of the number of atoms computed by Mr Perrin have completed the triumph of atomism. What makes it all the more convincing are the multiple correspondences between results obtained by totally different processes. […] We have arrived at such a point that, if there had been any discordances, we would not have been puzzled as to how to explain them; but fortunately there have not been any. The atom of the chemist is now a reality. (ibid, 91)

Poincaré's paper indicates a radical shift in his views about atomism. Before these experiments were known to him, Poincaré treats the atomic hypothesis at best as a useful fiction, which does not deserve to be treated as a genuine scientific hypothesis, since it was not subject to empirical testing. But this objection, which is purely methodological, could no longer hold after Perrin's experiments.

4. Challenging the traditional understanding of Poincaré's acceptance of atomism

How are we to interpret this radical change in Poincaré's view about the atomic hypothesis? One way of viewing the shift from believing atoms are fictions to believing they are real is to argue that Poincaré abandons his anti-realism towards unobservable entities and becomes a realist. According to Gardner, for example, "there was a gradual transition from an instrumentalistic to realistic acceptance of the atomic theory, because of gradual increases in its predictive power, the "testedness" of its hypotheses, the "determinateness" of its quantities, and because of resolutions of doubts about the acceptability of its basic explanatory concepts." (Gardner 1979, 1) For all the above reasons, Gardner suggests, many physicists, including Ostwald, accepted the existence of the atom. This acceptance seems to favour a scientific realist reading of the atomic hypothesis, since scientific realists commit to the unobservable entities postulated by empirically successful theories. Psillos suggests such a realist reading of Poincaré's 1912 paper:

> The point Poincaré made should be well-noted. Although atoms are invisible, we can (and have) amass(ed) much indirect evidence for their

> existence. In particular, all the different ways to calculate the number of atoms in a certain volume, and that there is a fixed number of atoms, make it highly plausible that these microscopic entities are real. Unless we accept their reality, we can hardly explain the observable phenomena. Nor can we explain that we can calculate with such a great precision how many atoms there are in a certain volume. In other words, it would be a great coincidence if atoms did not exist and yet all experimental findings were exactly those predicted by atomic theory. The very fact that the atomic hypothesis finds empirical support in the many and distinct domains in which atoms supposedly operate causally to generate certain observable phenomena gives good reason to accept that atoms are real. So, eliminative instrumentalism flies in the face of the fact that certain properties of atoms, including how many of those there are in a certain volume, can be fully determined by sound experimental practice. (Psillos 1999, 22)

Psillos' argument implies that Poincaré abandons his structural realism, for which he has constructed many sophisticated arguments and is integrated into his neo-Kantian philosophy, and becomes a scientific realist, a view which he clearly opposes in his previous work.[12] The implication of this reading is that after Perrin's experiments, Poincaré no longer has a structuralist stance towards theories but holds that the atomic hypothesis is true and that atoms, as described by it, exist and we have knowledge of their nature. In fact, Poincaré's argument might be seen as motivating 'entity realism', since it is based on the experimental detection of atoms. As developed by Ian Hacking and Nancy Cartwright, entity realism states that we know the existence of an entity if we have established causal contact with it independently of the theoretical descriptions associated with this entity that can change from one theory to another. As Hacking argues, the strongest justification for realism about unobservable entities is the fact that we can manipulate them. He claims, for the case of positrons and electrons, that "[s]o far as I'm concerned, if you can spray them, then they are real." (Hacking 1983, 23) However, it has been persuasively argued that this form of realism collapses into scientific realism (Psillos 1999, Massimi 2003). Since detection of an entity requires knowledge of its properties and causal powers, appeal to the theory that best describes these entities is necessary. As a consequence, the entity realist cannot establish that causal contact with an unobservable entity is possible without realism about the theory that describes what is been detected. This shows that we can either adopt a strong scientific realist interpretation of Poincaré's acceptance of the atom, or preserve his structuralism by showing that it is compatible with this acceptance.

To support the latter interpretation, I want to note an objection to reading Poincaré's argument as favouring scientific realism stemming from the metaphysical claim of scientific realism – belief in a mind-independent reality, which scientific theories reveal. Given Poincaré's Kantianism and belief that we have access only to phenomena and not to things in themselves, it is implausible to hold that he believes that the atom is a mind-independent entity that the atomic hypothesis reveals to us. On

[12] Stump (1989) also argues that Poincaré's argument establishes realism towards the atom and thus shows that he should not be regarded as instrumentalist. However, Stump also notes that Poincaré is not a scientific realist but has no reason to deny the existence of unobservable entities all together. Stump argues that Poincaré's position is similar to Shapere's (1969), who believes that the problem of whether theoretical terms refer to a particular unobservable entity should be resolved in a case-by-case manner (Stump 1989, 339).

the contrary, it is plausible to suggest that the atom of the chemist and physicist, which Poincaré accepts as real, simply becomes part of the phenomenal world. The atom of the chemist cannot be seen as the 'thing in itself', that causes the observed phenomena and on which all other entities supervene. The atom of the chemist simply becomes part of the phenomenal world.[13]

If the atom is not part of the mind-independent world then it seems that a scientific realist interpretation of Poincaré's argument is not tenable. Nevertheless, his 1912 paper does indicate a change in his attitude towards the atomic hypothesis. But how is this acceptance to be understood? Krips argues against the idea that Poincaré's acceptance of the atom, after Perrin's experiments, indicates a change of view towards the atomic hypothesis, that is, from instrumentalism to scientific realism. He claims that:

> there was a widespread late-nineteenth century methodological tradition which motivated the change in status of certain ontological claims - e.g., that atoms exist – from 'inaccessible to science' to 'scientifically acceptable' even though those claims were not strictly 'observable'. This methodological tradition is a hybrid of positivist and realist views. Thus, contrary to one popular view, the *fin de siècle* triumph of atomism is not to be seen as a triumph for a realist view of science. (Krips 1986, 43)

On this reading, Poincaré does not become a realist about the atomic hypothesis but the atomic hypothesis simply changes its status. Note the distinction Poincaré introduces in *Science and Hypothesis* between empirical, conventional and indifferent hypotheses.[14] Before Perrin's experiments, the atomic hypothesis was simply an indifferent hypothesis, making metaphysical claims about the nature of the unobservable reality. These claims, according to Poincaré, are not essential for deriving experimental results. Whether matter is infinitely divisible or has a fundamental, indivisible nature does not affect our predictions because the question does not have empirical significance. After Perrin's experiments, this changes: the atomic hypothesis has empirical nature; it makes predictions that can be subjected to experimental test. Therefore, Krips argues, the switch was not in Poincaré's views about scientific theories, but in his classification of the atomic hypothesis; from an indifferent hypothesis it becomes an empirical one.

---

[13] Poincaré makes an interesting claim about atoms being 'observable': "it seems so to speak, that we can see them since we know how to count them." (Poincaré 1913, 89) His criterion of acceptance of an unobservable entity extends from direct accessibility to our senses to detectable by measurement. However, one could see the notion of observability endorsed by Poincaré as having a broader meaning, along the lines of Dudley Shapere's (1982) notion of observability that goes beyond direct observation to what is experimentally detectable by instruments. An example of indirect observation, discussed by Shapere, includes detecting neutrinos that travel without interaction from the nucleus of the sun, and which interact with the detection device, serving as means of indirectly 'observing' the nucleus of the sun. However, such a liberal understanding of the term 'observable' would leave the distinction between scientific and structural realism unclear. Thus, the term 'observable' here should best be understood as 'detectable'. Also, note that 'detectable' or 'observable' does not equate with being part of the phenomenal world. The distinction between the phenomenal and noumenal world does not reduce to the observable-unobservable distinction.

[14] Poincaré's regards metaphysical hypotheses, such as hypotheses regarding the composition of matter, indifferent because they do not change the empirical predictions. Conventional hypotheses are not like the metaphysical hypotheses because they play a central function for the derivation of empirical content – they are constitutive in the sense that they are necessary presuppositions for the empirical content of a theory.

Krips' reading brings into light an important distinction which needs to be made. Which atom is Poincaré accepting? The atom of the physicist is a (divisible) particle that composes matter and obeys mechanical laws. Poincaré discusses the difficulties for the current physicists to employ the atomic hypothesis and explain known phenomena. The atom of the chemist, which Poincaré accepts, comes in different species which in different combinations gives rise to different kinds and chemical properties. The atom of the metaphysician, on the other hand, is an indivisible, fundamental particle, on which all other particles supervene. In light of this distinction, we should treat Poincaré's acceptance with care. He is not committed to the fundamental entity of the metaphysician but to the existence of some new phenomena that have been 'counted'. This acceptance makes perfect sense within a Kantian reading of Poincaré and does not entail abandonment of his structuralism. It can be seen as suggesting that since the atomic theory has become empirical, we can have a structural realist attitude towards it.

Drawing the distinction between the different meanings of atomism allows us to understand better what Poincaré aims to establish. Even though I have argued that a scientific realist reading of Poincaré's views is not plausible, it is important nonetheless to understand how his acceptance of the atom could be seen to challenge a structural realist reading of his philosophy. It is currently accepted that Poincaré's attitude towards scientific theories is structural realist. If Poincaré argues for the existence of an unobservable entity, then this reading is challenged. One cannot coherently be a structural realist and accept the existence of an unobservable entity and the properties assigned to it by the best available scientific theory. According to structural realism, we can know the relations between unobservable entities, but not their properties (their nature). We can differentiate three mutually exclusive views regarding unobservable entities, which structural realists can endorse. A structural realist can be (1) agnostic as to whether there are unobservable entities. Or, (2) she can hold that there are unobservable entities, but our epistemic restriction does not allow us to know their 'nature' (that is, their first order properties). Or (3) a structural realist can employ the argument for coherence between epistemology and metaphysics and suggest that since all we can know is relations and not the entities themselves, then we should eliminate the unobservable entities from our ontology. This version is compatible with Ladyman's (1998) ontic structural realism.

It is an open question as to whether Poincaré believes there are unobservable entities or he is agnostic. Whichever version of structural realism we believe is adopted by Poincaré, his acceptance of the atom clashes with it. If we take Poincaré's view to admit that there are unobservable entities of which we cannot know the properties, a view which is compatible at least with his (1902), this view is incompatible with his acceptance of the atom. The epistemic restriction from knowing the nature of the atom should forbid a structural realist from admitting its existence. We simply cannot hold both that, on the one hand, we cannot know anything about unobservable entities apart from the structure they give rise to, and, on the other hand, suggest that we have established epistemic access to an unobservable entity. The agnostic form of structural realism is also incompatible with Poincaré's acceptance of the atom, since it advocates agnosticism towards whether there are particular unobservable entities. Therefore, whichever form of structural realism is associated with Poincaré's philosophy of science in general, it cannot be consistent with his acceptance of an unobservable entity with some particular set of properties.

I have so far argued that Poincaré's acceptance of the atom does not indicate a shift from structural to scientific realism. However, I want to look more carefully at

the argument Poincaré develops and show, in light of the three different meanings of atomism mentioned above, that the argument is not only aimed at showing the shift in status of the atomic hypothesis, but is also aimed against fundamentalism. This argument, I argue, is perfectly compatible with Poincaré's structuralism and fits his general philosophy of science.

5. A closer look at Poincaré's argument

Let us examine carefully what exactly Poincaré states in his 1912 paper. According to him:

> The brilliant determinations of the number of atoms computed by Mr. Perrin have completed the triumph of atomism. What makes it all the more convincing are the multiple correspondences between results obtained by totally different processes. Not too long ago, we would have considered ourselves fortunate if the numbers thus derived had contained the same number of digits. We would not even have required that the first significant figure be the same; this first figure is now determined; and what is remarkable is that the most diverse properties of the atom have been considered. In the processes derived from the Brownian movement or in those in which the law of radiation is invoked, not the atoms have been counted directly, but the degrees of freedom. In the one in which we use the blue of the sky, the mechanical properties of the atoms no longer come into play; they are considered as causes of optical discontinuity. Finally, when radium is used, it is the emissions of projectiles that are counted. We have arrived at such a point that, if there had been any discordances, we would not have been puzzled as to how to explain them; but fortunately there have not been any. The atom of the chemist is now a reality. (Poincaré 1913, 90-91)

This, so far, seems to be a positive argument for the acceptance of the atom. It is this quotation that has given rise to the different interpretations and debates about Poincaré's realism towards the atomic hypothesis. However, the 'reality' of the atom is not the conclusion of Poincaré's argument, it is simply a premise of an argument which does not intend to motivate in a positive manner realism towards the atom. Let us see how this argument continues:

> The atom of the chemist is now a reality; but this does not mean that we are about to arrive at the ultimate elements of matter. When Democritus invented the atoms, he considered them as absolutely indivisible elements beyond which there is nothing to seek. That is what that means in Greek; and it is for this reason, after all, that he had invented them. Behind the atom, he wanted no more mystery. The atom of the chemist would therefore not have given him any satisfaction; for this atom is by no means indivisible; it is not truly an element; it is not free of mystery; *this atom is a world*. (ibid. 91, my emphasis)

Poincaré argues that even if we take Perrin's experiment to tell us that the atomic hypothesis is now a successful empirical theory, we should not conclude that we have reached the fundamental level of reality, as was initially intended by the construction

of atomism. To reconstruct the argument: the first premise of the argument is that the empirical determination of the atomic number by Perrin indicates that the atom is real. The second premise states that what we understand by 'atom' is an indivisible element of matter. The third premise is that the atom discovered by Perrin is divisible. Therefore, the atom discovered by Perrin is not really an 'atom', that is, the entity that Perrin has managed to empirically count, is not an indivisible element of reality.

Poincaré continues his argument by suggesting that the atom itself is composed of other entities; it is a complicated "solar system". According to him:

> Each new discovery in physics reveals a new complexity of the atom. And first of all the bodies which were believed to be simple, and which, in many respects behave exactly like simple bodies, are capable of being broken down into simpler ones still. […] This is not all. In the atoms we find other things: in it, first of all, we find electrons. Each atom therefore seems to be a sort of solar system in which some negative electrons playing the role of planets gravitate around a large positive electron which plays the role of central sun. […] But we have not come to the end. After electrons or atoms of electricity come the magnetons or atoms of magnetism. […] What then is a magneton? Is it something simple? No, if we do not wish to abandon Ampere's hypothesis of currents of particles. A magneton is therefore a vortex of electrons and our atom now becomes more and more complicated. (Poincaré 1913, 91-93)

This argument makes it clear that the question with which Poincaré is concerned is not whether we should be realists about unobservable entities such as the atom. Since the atomic hypothesis is empirically testable, leads to more predictions and is more fruitful, there is no question that we should accept it as an empirically successful theory. The question is whether we should think that we have found the ultimate element of reality.

Poincaré claims that our starting point was believing that matter is composed of atoms – understood as indivisible building blocks of matter. However, further discoveries reveal that atoms are themselves complex systems composed of other particles – electrons. Science, then, gives us no grounds to suspect that we will find a fundamental particle. What this argument shows is that we have inductive grounds to expect that we cannot find a fundamental level of nature. It is this argument which deserves attention and has passed unnoticed in the literature. It suggests that we cannot legitimately infer from the history of science that we will find a fundamental level of reality.

6. Fundamentalism and Structural Realism

I have argued that Poincaré's argument for the acceptance of the atom does not indicate a shift from structural to scientific realism but simply a shift in how Poincaré classifies the atomic hypothesis. This acceptance, however, needs to be understood with care as it indicates the complexity of the atomic hypothesis, which can be thought of as a conjunction of metaphysical, physical and chemical hypotheses. In this section I explain why Poincaré does not accept the metaphysical hypothesis of his atomist scientific realist opponents, even when he 'accepts the atom', and why his argument is perfectly compatible with his structuralism.

An argument against fundamentalism, relevant to Poincaré's, has been developed in the current literature by Jonathan Schaffer. According to Schaffer:

> The fundamentalist starts with (a) a hierarchical picture of nature as stratified into levels, adds (b) an assumption that there is a bottom level which is fundamental, and winds up, often enough, with (c) an ontological attitude according to which the entities of the fundamental level are primarily real, while any remaining contingent entities are at best derivative, if real at all. Thus […] the atomist claims that there are no macroentities at all but only fundamental entities in various arrangements. (Schaffer 2003, 498)

Schaffer questions the assumption that there is a fundamental level to nature for several reasons, amongst which is the alleged fact that such an assumption is not supported by modern physics. He suggests that the view that there is a bottom level, on which all the rest supervene, is highly problematic. He explains the commitment of the fundamentalist view as follows:

> The peripheral connotation of 'levels' include those of (a) a *supervenience structure*, ordered by asymmetric dependencies; (b) a realization structure, ordered by functional relations; and (c) a *nomological structure*, ordered by one-way bridge principle between families of lawfully interrelated properties. (ibid, 500)

Schaffer argues that we should question mereological fundamentalism on inductive and naturalistic grounds[15]:

> The history of science is a history of seeking ever-deeper structure. We have gone from 'the elements' to 'the atoms' to the subatomic electrons, protons and neutrons, to the zoo of 'elementary particles', to thinking that the hadrons are built out of quarks […] Should one not expect the future to be like the past? (ibid., 503)

Following Schaffer, Ladyman and Ross (2007) also question the intuition that the

> world comes in 'levels'. Contemporary science [...] gives no interesting content to this metaphor, and so a metaphysics built according to the PNC

[15] Kerry McKenzie (2011) opposes the plausibility of the inductivist argument. She doubts there is sufficient number of examples from the history of science to support the meta-induction. Most importantly, she agues that despite appearances, the inductivist argument is not naturalistically motivated because it presupposes that the same dependence relation is to be exemplified in future physics. She argues that "the insuperable problem with historic-inductive arguments against fundamentality such as Schaffer's is that they necessarily rest upon speculative assumptions regarding the metaphysics of future physics that are surely at odds with the naturalistic agenda." (McKenzie 2011, 248) She claims that questions regarding fundamentality can only be resolved internally, that is, within a particular physical theory and demonstrates how the claim of mereological fundamentality can be questioned within the S-matrix theory of strong interactions.

> [Principle of Naturalistic Closure[16]] should not reflect it." (Ladyman and Ross 2007, 54)

They explicitly side with Schaffer's inductive argument and claim that

> [a]rguably we do have inductive grounds for denying that there is a fundamental level since every time one has been posited, it has turned out not to be fundamental after all (ibid., 187)

Schaffer's argument against fundamentalism is illuminating for our understanding of Poincaré. Poincaré can be interpreted as defending Shaffer's argument against mereological atomism which is based on the observation that it is not supported by our current fundamental theories. Poincaré denies the presupposition of atomism that there is a bottom level to reality and suggests that even if atomism as a theory is false (that is, the atom is not an indivisible entity), such a theory still relies on the idea that there is a bottom level, even if that level is not the atom. Most importantly, Poincaré's argument is epistemic and not metaphysical. Poincaré and Schaffer remain agnostic as to whether there really is a fundamental level, whilst arguing that we have reasons not to believe that we will find such a level. As Schaffer argues:

> [W]ith regard to whether the complete microphysics (if such there be) will postulate particles, I once again council agnosticism. Of course, if one is assuming atomism again, I can see why one would expect particles in the final theory. But here the dogma is chasing its tail again. (Schaffer 2003, 505)

> [T]here are at least two perfectly good conceptions of the hierarchy of nature: fundamentality and infinite descent. The empirical evidence to date is neutral as to which structure science is reflecting. And so, concerning the proposition that there exists a fundamental level of nature, one should withhold belief. (ibid, 506)

Schaffer's argument, which I have shown to resemble Poincaré's 1912 argument, is clearly epistemic. It is compatible with there being fundamental entities, whilst concluding that it is very unlikely that we will discover them. This argument differs from the metaphysical argument defended by Ladyman and Ross, which holds that non-fundamentalism motivates ontic structural realism, claiming that "there is no fundamental level" on which all other levels supervene (Ladyman and Ross 2007, 178).

The metaphysical argument against fundamentalism, which denies that reality comes in levels and that there is a fundamental level on which the rest supervene, is compatible with Ladyman's ontic structural realism but also with agnostic epistemic structural realism, since the latter does not exclude that there might not be unobservable entities after all. If Poincaré's argument against fundamentalism was

[16] Ladyman and Ross define the Principle of Naturalistic Closure as follows "Any new metaphysical claim that is to be taken seriously at time *t* should be motivated by, and only by, the service it performs, if true, in showing how two or more specific scientific hypotheses, at least one of which is drawn from fundamental physics, jointly explain more than the sum of what is explained by the two hypotheses taken separately." (2007, 37)

metaphysical, it would be incompatible with the first kind of epistemic structural realism, according to which there are unobservable entities, the nature of which we cannot know. But the argument does not claim that our metaphysics must be coherent with our epistemology. It allows for reality to be, after all, composed of levels and for there to be a fundamental level on which all other levels supervene. Poincaré claims that given the failure of our past physical theories to find the fundamental level, we have grounds to infer that such a level might not be found, if it indeed exists, and thus motivates agnosticism with respect to whether there is such a level. The epistemic argument against fundamentalism, developed by Poincaré, is perfectly compatible with both forms of epistemic structural realism – the agnostic form, advocated by Worrall, and the one accepting the existence of unobservable entities. That is, agnosticism towards whether there is a fundamental level to reality on which all other levels supervene, is compatible with agnosticism regarding whether there are unobservable entities or believing there are unobservable entities but we cannot know their intrinsic properties.

It should be noted that both forms of epistemic structural realism are compatible with both fundamentalism and non-fundamentalism. Since both forms of epistemic structural realism leave open the possibility of there being unobservable entities, they are compatible with there being a fundamental level to reality, that is, fundamental entities on which all other entities supervene.[17]

7. Conclusion

I this paper I have argued that Poincaré's 1912 paper, in which he accepts the existence of the atom, does not indicate a shift from structural to scientific realism. I have presented his argument and explored why it could be seen as incompatible with Poincaré's structuralism and motivating scientific realism. After presenting the three different atomic hypotheses (metaphysical, physical and chemical), I side with Krips' reading of Poincaré's acceptance, which holds that Poincaré did not become a scientific realist, but the atomic hypothesis simply changed its status from a metaphysical to a scientific (empirical) theory. I have examined in detail Poincaré's argument and showed that it is not concerned with establishing the existence of an unobservable entity but with arguing against our ability to discover the fundamental level to reality. After explaining the anti-fundamentalism argument, I have shown that it is an epistemological argument that is compatible with Poincaré's structuralism.

Acknowledgments

This work was supported by the British Society for Philosophy of Science and The Royal Institute of Philosophy.

Bibliography

Achinstein P. (2007). Atom's Empirical Eve: Methodological Disputes and How to Evaluate Them. *Perspectives on Science*, 15 (3)

Cartwright, N. (1983) *How the Laws of Physics Lie*, Oxford: Oxford University Press

[17] Also, ontic structural realism is compatible with the fundamentalist thesis, despite the fact Ladyman and Ross (2007) appear to oppose the latter.

Domski, M. (2000) The Epistemological Foundations of Structural Realism: Poincaré and the Structure of Relations, University of Leeds, *Workshop for Research in History and Philosophy of Science* (unpublished manuscript)

Duhem, P. (1954 [1906]). *The Aim and Structure of Physical Theory*. Princeton: Princeton University Press

Duhem, P. (1996 [1913]) Logical Examination of Physical Theory, in *Essays in the History and Philosophy of Science* (eds. Roger Ariew and Peter Barker), Hackett Publishing Company

French, S. and Ladyman, J. (forthcoming), 'In Defence of Ontic Structural Realism' to appear in Alissa and Peter Bokulich (eds) *Boston Studies in the Philosophy of Science: Scientific Structuralism*, Boston University Press

Friedman, M. (1999) *Reconsidering Logical Positivism*. Cambridge: Cambridge University Press

Gardner M. (1979) Realism and Instrumentalism in the 19th century Atomism, *Philosophy of Science*, Vol. 46, 1, pp 1–34, The University of Chicago Press.

Giedymin, J. (1982) *Science and Convention: Essays on Henri Poincare's Philosophy of Science and the Conventionalist Tradition*, Oxford: Pergamon Press

Hacking, I. (1983) *Representing and Intervening*, Cambridge: Cambridge University Press

Krips, H. (1986) Atomism, Poincaré and Plank, *Studies in History and Philosophy of Science*, Vol. 17, No. 1, pp. 43–63

Ladyman, J. (1998). What is structural realism? *Studies in History and Philosophy of Science*. 29, 409–424

Ladyman, J. and Ross, D. (with Spurrett, D. and Collier, J.) (2007), *Every Thing Must Go: Metaphysics Naturalised*, Oxford: Oxford University Press

Laudan L. (1981). A Confutation of Convergent Realism, *Philosophy of Science*, 48, pp. 19–49

Massimi, M. (2003) Non-defensible Middle Ground for Experimental Realism: Why We Are Justified to Believe in Colored Quarks, *Philosophy of Science*, 71, pp. 36–60

Maxwell, G. (1962) The ontological status of theoretical entities, In H. Feigl & G. Maxwell (Eds.), *Minnesota Studies in the Philosophy of Science*, Vol. 3, pp. 3–14, Minneapolis: University of Minnesota Press

McKenzie, K. (2011) Arguing Against Fundamentality, *Studies in History and Philosophy of Modern Physics*, Vol. 42, 244–255

Morganti, M. (2004) On the preferability of Epistemic Structural Realism, *Synthese* 142, pp 81–107

Poincaré, H. (1963 [1913]) *Science and Mathematics: Last Essays*, Dover Publications

Poincaré, H. (2001 [1902]) Science and Hypothesis, in *The Value of Science Essential Writings of Henri Poincaré* (Stephen Gould ed.), The Modern Library

Psillos, S. (1999). Scientific realism: How science tracks truth. London: Routledge

Putnam, H. (1975) Philosophical Papers, Vol.1: *Mathematics, Matter and Method*, Cambridge: Cambridge University Press

Russell, B. (1927) *The Analysis of Matter*, London: George Allen & Unwin

Schaffer J. (2003) Is There a Fundamental Level?, *NOUS* 37: 3, pp 498–517

Worrall, J. (1989). Structural realism: The best of both worlds? *Dialectica*. 43, pp 99–124

Shapere, D. (1969) Notes Towards a Post-Positivist Interpretation of Science, in *The Legacy of Logical Positivism*, P. Achinstein and S. Barker (eds), Baltimore: John Hopkins Press

Shapere, D. (1982) The Concept of Observation in Science and Philosophy, *Philosophy of Science*, 49, pp. 485-525

Stump. D. (1989) Henri Poincare's Philosophy of Science, *Studies in the History and Philosophy of Science*, Vol 20, pp. 335-363

Zahar, E. (2007) *Why Science Needs Metaphysics*. (Chicago and La Salle: Open Court)