Unification and Revolution: A Paradigm for Paradigms

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Abstract
Incommensurability was Kuhn's worst mistake. If it is to be found anywhere in science, it would be in physics. But revolutions in theoretical physics all embody theoretical *unification*. Far from obliterating the idea that there is a persisting theoretical idea in physics, revolutions do just the opposite: they all actually exemplify the persisting idea of underlying unity. Furthermore, persistent acceptance of unifying theories in physics when empirically more successful disunified rivals can always be concocted means that physics makes a persistent implicit assumption concerning unity. To put it in Kuhnian terms, underlying unity is a paradigm for paradigms. We need a conception of science which represents problematic assumptions concerning the physical comprehensibility and knowability of the universe in the form of a hierarchy, these assumptions becoming less and less substantial and more and more such that their truth is required for science, or the pursuit of knowledge, to be possible at all, as one goes up the hierarchy. This hierarchical conception of science has important Kuhnian features, but also differs dramatically from the view Kuhn expounds in his *The Structure of Scientific Revolutions*. In this paper, I compare and contrast these two views in a much more detailed way than has been done hitherto. I show how the hierarchical view can be construed to emerge from Kuhn's view as it is modified to overcome objections. I argue that the hierarchical conception of science is to be preferred to Kuhn's view.

Keywords: T. S. Kuhn, incommensurability, unification, physical comprehensibility of the universe, metaphysical paradigm, science without revolutions.

1 Incommensurability, Kuhn and Faraday

Decades ago, I was a visiting research fellow at the Centre for Philosophy of Science, Pittsburgh University. I was sitting in my office in the great Cathedral of Learning when in came Thomas Kuhn, unannounced. We had never met before. There was no small talk. We plunged immediately into a ferocious but entirely friendly argument about incommensurability. He, of course, was for it, I was against. We argued for half an hour or so. I had well-prepared arguments, for I had argued with Paul Feyerabend about incommensurability on a number of occasions. I understand, in fact, that incommensurability was something that Feyerabend and Kuhn cooked up together. I failed completely to convince Feyerabend that incommensurability is a mistake. And on the occasion when I met him in Pittsburgh, I failed to convince Kuhn.

I admire Kuhn's *The Structure of Scientific Revolutions* enormously. It does, however, get some important things wrong. Its worst mistake is incommensurability.

It always astonished me that anyone took incommensurability seriously for a moment, especially as Michael Faraday solved the problem around 1834, long before Kuhn and Feyerabend invented it. In putting forward his new, revolutionary theory of electrolysis, Faraday encountered just the kind of problem Kuhn describes in *Structure*. Faraday's new theory not only contradicted existing theories of electrolysis: it contradicted the very terms then in use to describe the phenomena of electrolysis. These terms made theoretical presuppositions that clashed with Faraday's theory. The phenomena were described in such a way that Faraday's theory was excluded from the outset. For example, the term "pole", referring to what we today would call "electrode", carried the theoretical presupposition that a pole was a centre of an attractive or repulsive force. This clashed with Faraday's theory.

Faraday solved the problem by inventing, in collaboration with William Whewell and others, a whole series of observational terms deliberately designed to be neutral between the competing theories. Thus were born the terms we use today: electrode, electrolyte, electrolysis, anode, cathode, ion, anion, cation.[1]

This strategy of Faraday's can always succeed, I claim, whenever there are competing theories about the same, or overlapping, phenomena. It will always be possible to concoct observational terms that are neutral between the two theories, and which can be used to describe phenomena that constitute crucial experiments intended to decide between the two theories. If, for example, we wish to compare predictions of Newtonian mechanics and special relativity, we can describe experimental results employing relational notions of length, time and mass (related to this or that inertial reference frame). Both theories predict results described in this way. If Newtonian theory predicts an outcome of such and such *absolute* (non-relational) length, time interval or mass, it follows immediately that it predicts the same *relational* length, time interval or mass.

It is very striking that Kuhn seems nowhere to have considered the strategy just indicated. In *Structure* he does consider the quite different strategy of constructing an observation language that is entirely devoid of theoretical presuppositions, and very reasonably rejects the idea as one which cannot be realized. But that idea is quite different from Faraday's – which Kuhn just overlooks.[2]

But how seriously did Kuhn take incommensurability? What exactly did he mean by it? In *Structure*, in support of incommensurability, Kuhn argues that, in a revolutionary situation, the old and new paradigms contradict one another, depict different worlds, use different terminology or give different meanings to the same terminology, interpret some observational and experimental data differently, and give a different emphasis to how important it is to solve this or that empirical problem. All this, together with much of the rest of what Kuhn says in *Structure* concerning incommensurability, can be interpreted as amounting to no more than either psychological or sociological remarks about the difficulties those who accept different paradigms have in understanding one another, or epistemological or methodological remarks about the lack of decisive grounds for accepting and rejecting paradigms in revolutionary situations. None of this amounts to incommensurability in the strong sense that it is impossible to assess the respective scientific merits of two competing paradigms objectively.[3]

At two points in *Structure*, however, Kuhn does commit himself to defending incommensurability in this strong sense. First, he argues, in effect, that in order to assess the scientific merits of two paradigms objectively, we need either agreed "concrete operations and measurements that the scientist performs in his laboratory" or a "neutral observation-language, perhaps one designed to conform to the retinal imprints that mediate what the scientist sees" (Kuhn, 1970, p. 125). But laboratory "operations and measurements are paradigm-determined" (Kuhn, 1970, p. 126). And the task of constructing a "pure observation-language" free of theoretical presuppositions seems hopeless. The conclusion, for Kuhn, seems inescapable. There are no agreed empirical data which can provide an impartial basis for assessing the relative merits of the two paradigms. Incommensurability in the strong sense seems inescapable.

Second, Kuhn concludes *Structure* by claiming “We may…have to relinquish the notion…that changes of paradigm carry [us] closer and closer to the truth”.[4] This is a devastating admission. It amounts to declaring that we have no objective, rational grounds (however tentative) for holding that there is progress in knowledge across revolutions. All the previous sterling work of *Structure* in depicting the way science does make progress by means of the puzzle solving of normal science, the discovery of anomalies, the grudging recognition of crisis leading to fully fledged revolution is, with this single admission, thrown to the winds. The long, arduous, tortuous build-up to revolution has, as its culminating achievement – no progress in knowledge whatsoever. And the only ground for this extraordinary admission has to be incommensurability in a very strong sense. Not just in the revolutionary situation, but long afterwards, when the new paradigm has had ample time to prove its worth, there are still no objective, rational grounds for holding, even tentatively, that it constitutes progress in the sense that it is closer to the truth than the old paradigm.

Kuhn could have avoided this disastrous outcome if he had taken note of Faraday’s straightforward solution to the problem, in 1834, well over a century before incommensurability was invented.

2. Revolutions in Physics all Reveal the Persisting Theme of Unification

There is something even more seriously wrong with incommensurability. Were it to be found anywhere in science, it would be in theoretical physics.[5] But revolutions in theoretical physics have one striking feature in common: they all embody theoretical *unification*. Revolutions associated with Galileo, Newton, Lavoisier, Dalton, Faraday and Maxwell, Mendeleev, Rutherford, Einstein, Bohr, Schrödinger, Dirac, Tomonaga, Schwinger and Feynman, Yang and Mills, Weinberg and Salam, Gell-Mann and Zweig have all been unifying revolutions. Galileo contributed to the unification of terrestrial and astronomical phenomena by revealing phenomena in the heavens similar to those found on earth. Newton, in unifying Kepler and Galileo, unified terrestrial and astronomical motion. Maxwell’s theory of the electromagnetic field unified electricity, magnetism and optics, and subsequently radio, infrared, ultraviolet, X, and gamma rays. Special relativity brought greater unity to Maxwell’s theory, unified energy and mass by means of $E = mc^2$, and partially unified space and time to form space-time. General relativity unified gravitation and space-time by absorbing gravitation into a richer conception of space-time. The theory of elements and chemical compounds initiated by Lavoisier brought astonishing unification to chemistry, in reducing millions of different sorts of elementary substances to around the one hundred of the elements. Quantum theory and the theory of atomic structure brought massive unification to atomic theory, properties of matter, interactions between matter and light. Instead of nearly 100 elements plus electromagnetic radiation, the theory postulates just four entities: the electron, proton, neutron and photon. Instead of a multiplicity of laws concerning the chemical and physical properties of matter, there is Schrödinger’s equation. Quantum electrodynamics unifies quantum theory, special relativity and classical electrodynamics. The electro-weak theory of Weinberg and Salam partially unifies the electromagnetic and weak forces. The quark theory of Gell-Mann and Zweig brought greater unity to the theory of fundamental particles: a large number of hadrons were reduced to just six quarks. Quantum chromodynamics brought further unification to the theory of fundamental particles by providing a quantum theory of the strong force. The standard model, the current quantum theory of fundamental particles and the forces between them, partially unifies the electromagnetic, weak and strong force. The unification is only partial because the different forces are all locally gauge invariant, but different kinds of locally gauge invariant forces nevertheless, observing different symmetries. And the theory postulates a number of distinct particles with different, even though related, properties. Supersymmetry seeks to unify fermions and bosons. Superstring theory attempts to reduce all particles to just one kind of entity – the quantum string in ten or eleven dimensions of space-time, observing just one law of evolution. It seeks to unify the standard model and general relativity.

This persistent theme of theoretical unification through revolutions in physics indicates that there is something very seriously wrong with Kuhn's idea that nothing theoretical persists through revolutions. As one author has remarked "*Far from obliterating the idea that there is a persisting theoretical idea in physics, revolutions do just the opposite in that they all themselves actually exemplify the persisting idea of underlying unity!*".[6]

But is there really a persistent thesis of theoretical unity here? Does not unification mean different things in these diverse cases? Elsewhere a detailed account has been put forward as to what it means to say of a physical theory that it is unified.[7] According to this view, all the above kinds of unification are varieties of just one generic notion of unification. I now attempt, very briefly, to explain the point.

A key problem confronting any account of theoretical unity is that any theory, however beautifully unified, can always be reformulated to become horribly disunified, and *vice versa*.[8] It is this problem that most accounts fail to solve.[9] In order to solve it we need to appreciate that unity is a feature, not of the theory itself, but rather of what it asserts about the world – the *content* of the theory, in other words. Varying the formulation has no affect on the degree of unity of the theory, as long as the content remains the same throughout the changes of formulation.

We can now define theoretical unity like this. In order to be unified, the content of a dynamic physical theory must be such that, what the theory asserts to exist that determines the way events evolve in space and time, *must be precisely the same* throughout all the possible phenomena to which the theory applies. Or, put another way, the content of the dynamic laws governing the way events evolve, specified by the theory, must be the same for all possible phenomena to which the theory applies. If there are different laws for N distinct ranges of phenomena, the degree of disunity of the theory equals N. For unity we require N = 1.

There is now a refinement. The content of the laws governing the way events evolve may differ *in different ways and to different extents* as one moves around in the space, S, of all possible phenomena to which the theory in question applies. This content may differ in different space-time regions; or for different values of variables, such as mass or charge; or the theory may postulate more than one force, one operating in one region of the space S, another operating in another region of S; or the theory may postulate different kinds of entity, particles with different dynamic properties for example, one kind present in one region of S, another present in another region of S. According to the view under discussion, eight different kinds of disunity can be distinguished in this way.

All the apparently diverse unifications achieved in physics, mentioned above, eliminate disunity of one or other of these eight kinds of disunity.[10] We have here, in short, a unified account of theoretical disunity which reveals that all the different kinds of unification achieved in theoretical physics eliminate disunity of one or other of the eight kinds, all of which are aspects of the same basic notion of unity. And this notion holds that, in order to be unified, a theory must be such that the same laws govern the evolution of events throughout all the possible phenomena to which the theory applies.

The upshot is that, even though different kinds of unification have been achieved in physics as a result of theoretical revolutions, nevertheless a common theme, a common thesis, runs through all of them.

3. Is Theoretical Unity Presupposed?

Has physics discovered theoretical unity, again and again, in a thoroughly open-minded way, without prejudging the matter, without *presupposing, from the outset as it were, that unity exists in nature to be discovered*? Or, on the contrary, does the whole enterprise of physics just take for granted that there is some kind of underlying unity in nature, the thesis that this exists being a persistent, if perhaps implicit, item of scientific knowledge? I now argue that the latter is the case. This massively intensifies the charge against Kuhn, as we shall see.

Consider any accepted, unified fundamental physical theory, T (Newtonian theory, classical electrodynamics, quantum theory, general relativity, QED, or the standard model). We can concoct as many empirically more successful but disunified rivals to T as we please by modifying T in an entirely arbitrary, ad hoc fashion so that the new theory, T*, successful predicts everything T predicts, is not refuted where T is ostensibly refuted, and successfully predicts phenomena T fails to predict.[11] These empirically more successful rivals quite properly never get considered for a moment in scientific practice precisely because they are disunified. Now comes the crucial point. In persistently rejecting – or rather ignoring – these endlessly many empirically more successful rivals to T on the grounds that they are disastrously *disunified*, physics thereby makes a big, implicit, persistent assumption: the universe is such that no disastrously disunified theory is true.[12]

Suppose physicists only accepted theories that postulate atoms, and persistently rejected theories that postulate different basic physical entities, such as fields — even though many field theories can easily be, and have been, formulated which are even more empirically successful than the atomic theories — the implication would surely be quite clear. Physicists would just be assuming that the world is made up of atoms, all other possibilities being excluded from consideration. The atomic assumption would be built into the way the scientific community accepts and rejects theories — built into the implicit *methods* of the community, methods which include: reject all theories that postulate entities other than atoms, whatever their empirical success might be. The scientific community would accept the assumption: the universe is such that no non-atomic theory is true.

Analogous considerations arise in connection with the persistent acceptance of unified theories, even though endlessly many empirically more successful disunified rivals can be concocted. There appear to be no grounds for holding that a big assumption is implicitly being made in the first case, but no such assumption is being made in the second one.

Thus, in persistently ignoring empirically more successful, disunified rivals to accepted theories, physics makes a persistent, substantial metaphysical assumption: the universe is such that all precise, seriously disunified physical theories are false.[13] This assumption has been implicit in the methods of physics since Galileo. It has persisted throughout all theoretical revolutions from Galileo's time to our own. It might be said to be a paradigm for the assessment of Kuhnian paradigms. It is accepted as a permanent item of scientific knowledge independent of empirical considerations – even, in a sense, as we have seen, in violation of empirical considerations.

It is at once clear that the picture of science Kuhn gives us in *Structure* is very seriously inadequate. But so too are all those other views of science which take what may be called *standard empiricism* for granted. By standard empiricism I mean the doctrine that, in science, all claims to knowledge must be decided, in the end, on the basis of evidence, considerations of simplicity, unity or explanatory power being taken into account possibly as well, the crucial point being, however, that *no substantial thesis about the world can be accepted permanently as a part of scientific knowledge independently of evidence* (let alone in violation of evidence). Standard empiricism is a component of inductivism, hypothetico-deductivism, conventionalism, Bayesianism, constructive empiricism, most versions of scientific realism, and the views of Popper, Kuhn, Lakatos and most contemporary philosophers of science. It is taken for granted by most scientists. And yet, as we have seen, it is untenable.

4. A New Conception of Science: Aim-Oriented Empiricism

We need a new conception of science, one which acknowledges explicitly the permanent metaphysical[14] assumption concerning unity that is implicit in those methods of physics which require seriously disunified theories to be rejected. This new conception of science may be called *aim-oriented empiricism*. It is depicted in figure 1. Aim-oriented empiricism (AOE) is, in some respects, strikingly similar to Kuhn's picture of science although, in other respects, it is dramatically different. Elsewhere, AOE has been expounded and defended in great detail.[15] Here, I will be as brief as I can.

The basic idea of AOE is to represent the metaphysical assumption of physics – implicit in the persistent acceptance of unified theories only – in the form of a hierarchy of assumptions concerning the comprehensibility and knowability of the universe. These assumptions assert less and less as one goes up the hierarchy, and thus become increasingly likely to be true; and they become more and more nearly such that their truth is required for science, or the pursuit of knowledge, to be possible at all. In this way a framework of relatively insubstantial, unproblematic, fixed assumptions and associated methods is created within which much more substantial and problematic assumptions and associated methods can be changed, and indeed improved, as scientific knowledge improves. Put another way, a framework of relatively unspecific, unproblematic, fixed *aims* and methods is created within which much more specific and problematic aims and methods evolve as scientific knowledge evolves. (Science has the aim, at each level, from 7 to 3, to discover in what precise way the relevant assumption is true, assumptions implicit in aims becoming increasingly substantial and problematic as one descends from

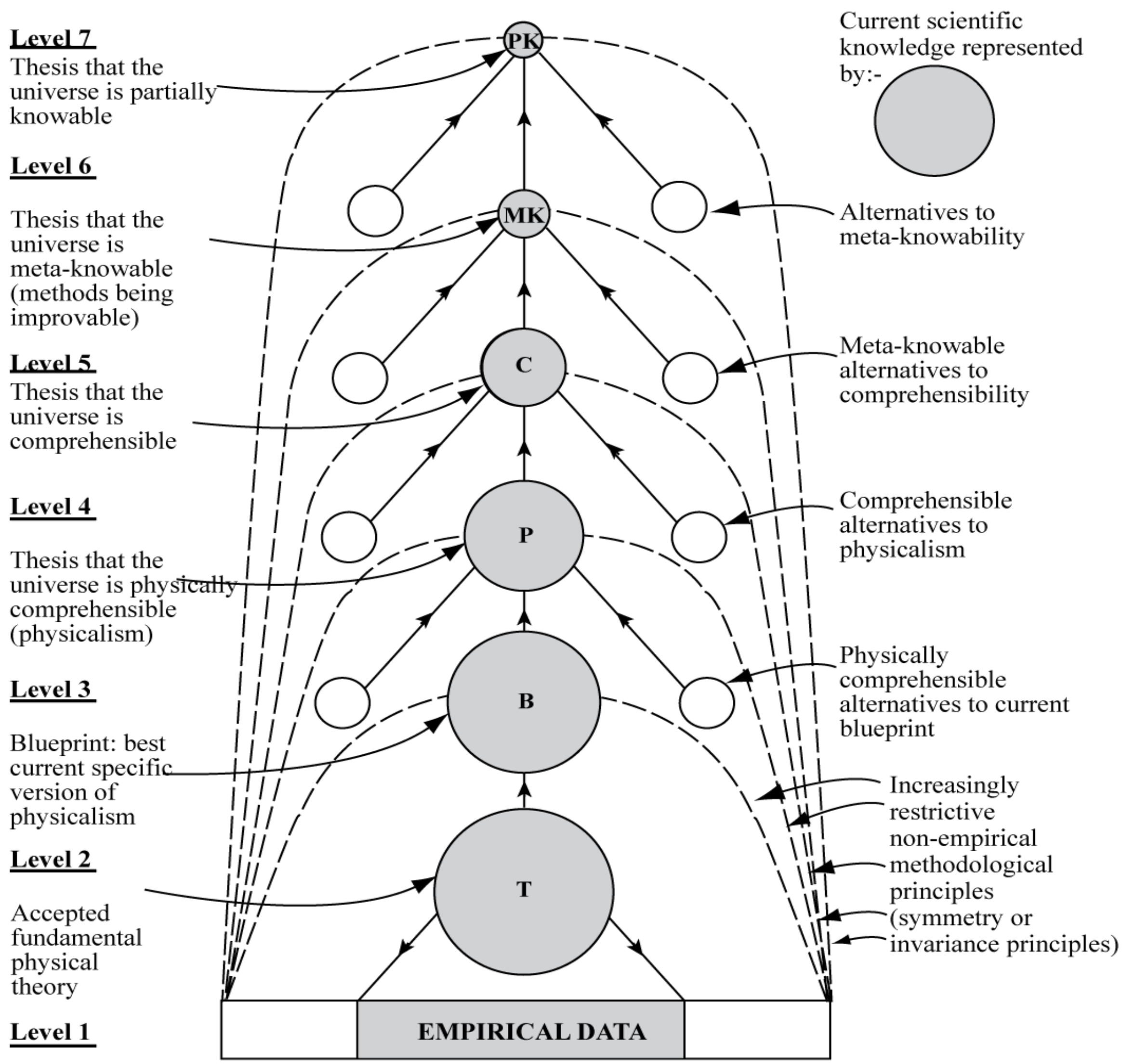

Figure 1: Aim-Oriented Empiricism

level 7 to level 3.) At any level, from 6 to 3, that assumption is accepted which (a) accords best with assumptions above in the hierarchy, and (b) is associated with the most empirically progressive research programme, or holds out the greatest promise of stimulating such a programme. There is thus something like positive feedback between improving knowledge, and improving aims-and-methods, improving knowledge-about-how-to-improve-knowledge. This is the nub of scientific rationality, the methodological key to the unprecedented success of science.[16] Science adapts its nature to what it discovers about the nature of the universe.

At level 7, there is the assumption that the universe is such that we can acquire some knowledge of our local circumstances. If this minimal assumption is false, we have had it whatever we assume. It can never be in our interests to abandon this assumption. At level 6 we have the more substantial and risky assumption that the universe is such that we can learn how to improve methods for improving knowledge. This promises to be too fruitful for progress in knowledge not to be accepted. At level 5 there is the assumption that the universe is comprehensible in some way or other – it being such that something exists which provides in principle one kind of explanation for all phenomena. At level 4 there is the even more substantial assumption of *physicalism*, interpreted here to be the thesis that the universe is *physically* comprehensible, there being some kind of invariant physical entity, pervading all phenomena which (together with instantaneous states of affairs) determines (perhaps probabilistically) how events unfold in space and time. The universe is such, in other words, that the true physical "theory of everything" is unified,[17] or fully explanatory in character. At level 3 there is the even more substantial assumption that the universe is physically comprehensible in some more or less specific way. Superstring theory, or M-theory, might be this assumption today – or perhaps a doctrine that might be called Lagrangianism.[18] At level 2 we have currently accepted fundamental theories of physics: at present, the standard model, and general relativity. At level 1 we have accepted empirical data – low level experimental laws.

This hierarchy of metaphysical theses may seem, at first sight, somewhat baroque, but it should be noted that something like it is to be found at the empirical level. There are, at the lowest level of this empirical hierarchy, the particular results of experiments performed at specific times and places. Then, above these, there are low-level experimental laws, asserting that each experimental result is a repeatable effect. Next up, there are empirical laws such as Hooke's law, Ohm's law or the gas laws. Above these there are such physical laws as those of electrostatics or of thermodynamics. And above these there are theories which have been refuted, but which can be "derived", when appropriate limits are taken, from accepted fundamental theory – as Newtonian theory can be "derived" from general relativity. This informal empirical hierarchy exists in part for precisely the same epistemological and methodological reasons that I have indicated for creating the hierarchy of metaphysical theses: so that relatively contentless and secure theses (at the bottom of the empirical hierarchy) may be distinguished from more contentful and insecure theses (further up the empirical hierarchy) to facilitate pinpointing what needs to be revised, and how, should the need for revision arise. That such a hierarchy exists at the empirical level provides support for my claim that we need to adopt such a hierarchy at the metaphysical level.

The argument for AOE comes in two stages. First, there is the argument, sketched above, that persistent acceptance of unified theories means physics makes a persistent, substantial, highly problematic and implicit metaphysical assumption about the universe. Once this first stage is accepted there are then, second, the following four distinct arguments in support of AOE.

1. AOE is more rigorous than all rival standard empiricist views of science in that it alone makes explicit, and so open to criticism and improvement, substantial, influential, highly problematic and implicit metaphysical assumptions of science.[19]

2. AOE provides us with the best methodological framework for the progressive improvement of the metaphysical assumptions of physics. It does this in part by concentrating criticism and the development of new ideas where this is most likely to be fruitful, low down in the hierarchy, at levels 2 and 3, and possibly 4. It also does this by ensuring that new ideas developed at these levels are constrained by empirical knowledge at level 1 and accepted assumptions higher up in the hierarchy, at levels 5 and above.[20]

3. AOE, when generalized to take into account other natural sciences besides physics, does better justice to scientific practice than any other view – as long as it is accepted that scientific practice is influenced by the scientific community's long-standing acceptance of the untenable view of SE (which serves to obscure and subvert somewhat explicit implementation of AOE).[21]

4. AOE solves at least five fundamental problems in the philosophy of science: the problem of induction;[22] the problem of how revolutionary new theories are discovered, especially in physics;[23] the problem of explicating precisely what it means to say of a physical theory that it is simple, unified or explanatory;[24] the problem of justifying persistent preference in physics for simple, unified or explanatory theories, and the problem of specifying precisely what scientific method ought to be.[25] In addition, AOE has a significant implication for the solution to the problem of verisimilitude.[26] The capacity to solve fundamental problems in the philosophy of science should be regarded as an important requirement any view of science needs to satisfy if it is to be judged adequate. AOE satisfies this requirement. No rival view does to the same extent.

We need a revolution in our whole conception of natural science. AOE ought to become the new orthodoxy, accepted and put into practice by the scientific community. A basic task for philosophers of science today is to get across to the scientific community a sense of just how decisive are the arguments against standard empiricism and for aim-oriented empiricism.

5. Kuhn and Aim-Oriented Empiricism: A Comparison

To what extent does AOE incorporate Kuhnian features, to what extent is it quite different from Kuhn? My answer may seem somewhat paradoxical.

According to AOE, we can see natural science since Galileo as having one fixed, super paradigm, namely the level 4 metaphysical thesis of physicalism – the precise and demanding thesis that the universe is physically comprehensible. This transforms science since Galileo into one long period of normal science – which is, at one and the same time, highly Kuhnian and wholly non-Kuhnian.

Before I attempt to explain how AOE is able to magic away Kuhnian revolutions and transform centuries of intermittent scientific revolutions into one long phase of normal science, let me first address the question of how AOE is able to give any support to normal science in any circumstances whatsoever.

The point is this. The inspiration for AOE comes from Popper, not Kuhn, in that the whole idea is to modify science so that it makes explicit, and so criticizable and rationally improvable assumptions that are substantial, influential, problematic and implicit. AOE is, if anything, more Popperian than Popper himself, in that it subjects more that is associated with science to an onslaught of critical scrutiny. So how can AOE hold Kuhnian normal science to be good science in any circumstances whatsoever? Popper, entirely understandably, resoundingly condemned Kuhnian normal science. He recognized that it exists. Indeed, he claimed to have discovered it himself decades before Kuhn (Popper, 1970, p. 51). But for Popper "The 'normal' scientist, as described by Kuhn, has been badly taught. He has been taught in a dogmatic spirit: he is a victim of indoctrination." And Popper went on to say of normal science that he saw in it "a danger to science and, indeed, to our civilization" (Popper, 1970, p. 53).

All this makes perfectly good sense when viewed from the perspective of Popper's falsificationism. From this perspective, the whole point of experimental work is to subject scientific theories to as severe attempted empirical falsification as possible. But for Kuhn, during normal science, quite properly, it is not the paradigm, or theory, that is put to the test, but the scientist himself. If a paradigm fails successfully to predict some phenomenon, within the context of normal science, it is not the paradigm that has been falsified, but the scientist who has failed to solve the scientific "puzzle" that confronted him. This must be, for Popper, absolute anathema, the very opposite of what it is to be scientific. How then, to repeat the question, can AOE approve of anything resembling normal science?

Kuhn argues that the dogmatic attitude of normal science is necessary for science to make progress. Applying a paradigm to new phenomena, or to old phenomena with increasing accuracy, is often extremely difficult. If every failure was regarded as a failure of the paradigm rather than of the scientist, paradigms would be rejected before the full range of their successful applications had been discovered. As a result of refusing to reject a paradigm until the limits of its successes have been reached, scientists put themselves into a much better position to develop and apply a new paradigm. For reasons such as these, normal science, despite being ostensibly designed to discover only the expected, is actually uniquely effective in disclosing novelty.

To this one might add that, as long as physicists seek to apply the paradigm to an ever greater range of phenomena with ever greater accuracy, the paradigm is in fact being subjected to empirical testing, whatever the attitude of the scientists doing the work may be – as long as persistent predictive failure is taken seriously, in the way Kuhn describes (Kuhn, 1970, sections VI-VIII).

In short, Kuhn gives excellent reasons as to why normal science is necessary for scientific progress – reasons which Popper just ignores. AOE does not make the same mistake. It holds that much scientific work ought indeed to resemble Kuhn's normal science, in part for the reasons just indicated. But there is an even more important reason. According to AOE, and in sharp contrast to Popper's falsificationism, theoretical physics accepts a level 3 metaphysical assumption or "blueprint", which exercises a powerful constraint on what kind of new theory physicists can try to develop, or can consider or accept. This metaphysical blueprint has a role somewhat similar, in some respects, to Kuhn's paradigm, and theoretical physics, working within the constraints of the blueprint, its non-empirical methods set by the blueprint, has some features of Kuhn's normal science.

Furthermore, according to AOE, other branches of natural science less fundamental than theoretical physics invariably presuppose relevant parts of more fundamental branches. Thus chemistry presupposes relevant parts of atomic theory and quantum theory; biology relevant parts of chemistry; astronomy relevant parts of physics. Such presuppositions of a science have a role, for that science, that is analogous to the role that the current level 3 blueprint, or the level 4 thesis of physicalism, has for theoretical physics. The presuppositions act as a powerful constraint on theorizing within the science. They set non-empirical methods for that science. Such presuppositions have a role, in other words, which is similar, in important respects, to Kuhn's paradigms. They constitute paradigms for the assessment of paradigms, in that they persist through theoretical revolutions in the science in question. Viewed from an AOE perspective, one can readily see how and why much of science seems much more like Kuhnian puzzle-solving rather than Popperian severe testing.

In passing, I might mention that there are two other respects in which AOE resembles the picture of science depicted by Kuhn's *Structure*. First, Kuhn is at pains to emphasize that the paradigm is more fundamental than rules or methods. Methods stem from the currently accepted paradigm (Kuhn, 1970, section V: see especially p. 41-42). AOE holds a somewhat similar view, in that metaphysical assumptions, especially those low down in the hierarchy, at levels 3 and 4, set the non-empirical methods of theoretical physics. AOE is, perhaps, more concerned to emphasize the two-way traffic between methods and metaphysics than Kuhn is in *Structure*.

Second, metaphysical assumptions low down in the hierarchy of AOE undergo dramatic changes somewhat similar to the revolutionary changes in paradigm depicted by Kuhn during scientific revolutions. Furthermore, in some cases, the metaphysical assumptions in question are all but identical to Kuhnian paradigms. Initially, with the birth of modern science in the 16th and 17th centuries, the level 3 blueprint assumption of AOE took the form of the corpuscular hypothesis: the world is made up of minute, rigid particles which interact by contact. After Newton, and with Boscovich, this became the doctrine that the world is made up of massive point-particles surrounded by rigid, spherically symmetrical fields of force which become alternatively repulsive and attractive as one moves away from the particle. This became the unified field view of Faraday and Einstein, particles being merely especially intense regions of the field. This in turn became, after quantum theory, the quantum entity, whatever that might be, which in turn became the quantum field which, in turn became, perhaps, the quantum string of M-theory of today.

Some of these are identified by Kuhn as paradigms – for example, the corpuscular hypothesis (Kuhn, 1970, p. 41).

6. How Aim-Oriented Empiricism Tames Kuhnian Revolutions

So far I have argued that AOE agrees with Kuhn in holding that something like normal science is necessary for scientific progress, and shares some other features with Kuhn's picture of science as well. What I have not yet explained is how AOE can conceivably depict science since Galileo as one long phase of normal science. Scientific revolutions have undoubtedly occurred during this period. How can AOE magic them away?

The crucial point to note is that, during much of this time, the scientific community has taken for granted one or other version of standard empiricism. In Newton's time, science was understood quite differently as natural philosophy. This intermingled science, metaphysics, epistemology, methodology, philosophy, even theology, and was, in a way, much closer to the conception of science inherent in AOE. But then standard empiricism came to prevail, in part, I believe, as a consequence of the immense impact of Newton, his apparent success in deriving his law of gravitation from the phenomena by induction, his claim to have done this, and the influence of his "rules of reasoning in philosophy", generally misunderstood.[27] After Newton's great success, scientists came to believe that they had a definite method to employ, the inductive method of science, which they could be confident would meet with success. Observation, experiment and testable theory are all-important in science, and philosophy, metaphysics, methodology, epistemology can all be ignored.

As a result of this general acceptance of standard empiricism, whether in the form of inductivism or hypothetico-deductivism, the metaphysical assumptions of science are repressed. There can be no sustained discussion of highly influential and problematic metaphysical assumptions at levels 3 and 4 as an integral part of the public face of science. It is this suppression of influential, problematic metaphysical presuppositions that creates, artificially and unnecessarily, the drama, the ruptures, the crises, the changes of world view, the breakdown of rationality, of Kuhn's scientific revolutions. Pursue science in accordance with the edicts of AOE, and the very distinction between normal and revolutionary science begins to disappear.

In order to see this, let us do a bit of imaginative, counterfactual history, and suppose that, from Newton's time onwards, the scientific community accepted and implemented AOE. At once, metaphysical theses at levels 3 to 7 become basic items of scientific knowledge. Physicalism at level 4 asserts that the universe is such that the true physical "theory of everything" is unified (in all eight ways, with N = 1 in each case). This means that only a theory of everything can be precisely true of anything. In so far as physics puts forward theories about restricted ranges of phenomena, physics will advance from one false theory to another. Such a mode of advance is to be expected, and is a sign of progress as long as each theory achieves greater unification and greater empirical success than its predecessor.[28] One consequence is that dynamical physical theories of restricted ranges of phenomena only are all false whatever their predictive and explanatory power may be. They are refuted on metaphysical grounds, as it were, even if not on empirical grounds, and hence some sustained effort needs to be put into developing better theories, even in the absence of empirical difficulties.

Thus, in addition to the tasks of normal science described by Kuhn, theoretical physics, pursued explicitly in accordance with AOE, acquires the new, objective tasks of discovering how to modify, to improve, theories at level 2, and the thesis at level 3, so as to remove, or at least lessen, contradictions between theories, and between levels 2, 3 and 4. In particular, physicists will explore modifications to the thesis at level 3 in an attempt to develop a thesis that accords better with the thesis at level 4. There will be the attempt to formulate more precisely the best available thesis at level 3 in an attempt to turn the metaphysical thesis into an empirically testable theory. The task of creating a new fundamental physical theory all but meets Kuhn's requirements for puzzle solving, in that the task is specified, the rules of the game are specified, and what is to count as the solution is specified as well. And these tasks need to be performed even if existing theories face no serious empirical refutations, there are no Kuhnian anomalies, and no Kuhnian crisis. Dramatically new theories arise as a result, not of abrupt Kuhnian revolution, but of long-standing, gradual *evolution*, made up of many small modifications of levels 2 and 3, constrained by levels 1 and 4. Many sequences of steps no doubt lead down blind alleys; just one or two sequences lead to a successful new unifying theory.

There is here a largely unexplored, rich field of research in counterfactual history of science: to redo theoretical physics, from Galileo onwards, in the manner indicated, implementing the fallible but rational method of discovery of AOE. Some modest contributions to this field have already been made. The rules of the game have been explicated and, in particular, the different ways a theory can be unified or disunified have been precisely specified (see note 11). It has been shown how, beginning with the 17^{th} century blueprint of the corpuscular hypothesis, the concern to get this to accord better with the level 4 thesis of physicalism, and nothing else, leads one to modify the blueprint so that it becomes, in turn, the Boscovich point-atom blueprint, the unified field blueprint, and even something that has intimations of special relativity (Maxwell, 1998, pp. 80-89). It has been argued that Einstein, in creating his special and general theories of relativity, exploited AOE or something very close to it quite explicitly, perhaps for the first time in the history of physics.[29] It has been argued that the development of a new fundamentally probabilistic blueprint for physics might make sense of the mysteries of quantum theory, and lead to a version of the theory testably distinct from orthodox quantum theory.[30] And an alternative to the level 4 thesis of physicalism has even been put forward.[31]

If AOE is not put explicitly into practice, and one or other version of standard empiricism is accepted instead, there can be no metaphysical refutation of an empirically successful physical theory, and no explicit exploitation of the rational method of discovery of AOE in the public domain of physics – even if, privately, as it were, individual physicists may put something like this into practice in developing new theories. Instead of new theories being developed in a collaborative way even before existing accepted theories have run into empirical difficulties, the tendency will be for most physicists to work at extending the predictive range and accuracy of existing theories, thus engaging in Kuhnian normal science. The outcome will tend to be anomaly, crisis, revolution, as depicted by Kuhn, the product of trying to do physics in accordance with standard empiricism. In short, the Kuhnian contrast between normal and revolutionary science is an artefact of attempting to do science in accordance with the untenable conception of science of standard empiricism. Put AOE explicitly into scientific practice instead, and the very distinction between normal and revolutionary science will tend to disappear.

It must be admitted, however, that actual physics does not altogether accord with the Kuhnian account. It is not empirical problems or Kuhnian crisis that has driven so many theoretical physicists to work at unifying quantum theory and general relativity by means of superstring theory, loop quantum gravity, or in some other way. Superstring theory might indeed be taken as indicative of the kind of metaphysical normal research which AOE advocates, and which Kuhn entirely overlooks, even as a possibility. Superstring theory has been developed gradually over decades, as a major research programme, by thousands of physicists engaged in what might well be regarded as theoretical puzzle solving. The central aim is to discover the true, unified "theory of everything". And yet superstring theory has not yet come up with one single successful empirical prediction. It is, so far, pure metaphysics.[32] All this accords beautifully with the kind of normal metaphysical research which AOE holds physics ought to do.[33] Perhaps physics already puts AOE into practice, even though most scientists still pay allegiance to standard empiricism.[34]

There is an additional adverse consequence, stemming from the attempt to do physics in accordance with standard empiricism, which deserves to be mentioned. Failure explicitly to improve level 3 metaphysical ideas means that the ideas that are (implicitly) accepted, far from leading the way to the development of new theories, in the manner of Einstein, instead do not even keep pace with new theories that are developed and, as a result, impede the interpretation and acceptance of these new theories. Thus, acceptance of the corpuscular hypothesis impeded the interpretation and acceptance of Newtonian theory. Huygens, in a letter to Leibniz, wrote: “Concerning the Cause of the flux given by M. Newton, I am by no means satisfied [by it], nor by all the other Theories that he builds upon his Principle of Attraction, which seems to me absurd. . . I have often wondered how he could have given himself all the trouble of making such a number of investigations and difficult calculations that have no other foundation that this very principle” (Koyré, 1965, pp. 117-8). Newton in a sense agreed, as is indicated by his remark: “That gravity should be innate, inherent and essential to matter, so that one body may act upon another, at a distance through a vacuum, without the mediation of anything else. . . is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it” (Burtt, 1932, pp. 265-6). Once Boscovich’s subsequent blueprint is accepted, these objections disappear. Another example is provided by Maxwell’s theory of electrodynamics. Maxwell himself, and most of his contemporaries and immediate successors, sought to interpret the electromagnetic field in terms of a material substratum, the hypothetical aether, itself to be understood in Newtonian or Boscovichean terms. An immense amount of effort was put into trying to understand Maxwell’s field equations in terms of the aether. But once the unified field blueprint is accepted, Maxwell’s theory emerges as perfectly comprehensible and acceptable as it stands: the aether would be an unnecessary complication. And, as I have already indicated, yet another example of this phenomenon may be provided by quantum theory. Attempts are made to interpret quantum theory implicitly presupposing determinism and, when these fail, instrumentalism is assumed instead, which creates its own problems (Maxwell, 1993b). What for decades was overlooked, and still tends to be overlooked, is the possibility of interpreting quantum theory in terms of what might be a more relevant fundamentally probabilistic metaphysical outlook. Again and again, understanding and even acceptance of new theories is impeded by implicit acceptance of outdated metaphysical ideas – outdated because they have not been subjected to explicit criticism and attempted improvement.

There is another consideration which strengthens my claim that physics since Galileo, if it had been pursued explicitly in accordance with aim-oriented empiricism, would have looked much more like one long phase of Kuhnian normal science. It comes from a proposed solution to the problem of verisimilitude (Maxwell, 2007, pp. 393-400 430-433). This makes use of a notion of “approximate derivation”. In order to illustrate this notion, consider the approximate derivation of Kepler’s law that planets move in ellipses from Newton. First, Newton is restricted to the solar system. Then, one lets the masses of the planets tend to zero. In the limit the orbits become precisely Keplerian. Then, one reinterprets what has been derived so that it applies to the solar system, the planets acquiring mass. We have Kepler's law. It is, of course, the third step which renders the outcome incompatible with Newton. "Approximate derivations" of the kind here illustrated are to be found everywhere in physics. Physicists neglect higher terms, and make other approximations, all the time in deriving laws from theories. One might almost say "derivation" in physics means "approximate derivation". So, in terms of this physicists' notion of derivation, we can declare that Newtonian theory can be derived from general relativity, and Kepler's and Galileo's laws can be derived from Newtonian theory, even though, strictly and logically speaking, these successive theories are all incompatible with one another.

This makes the advance of physics through revolutions in retrospect much more genuinely accumulative, and similar to Kuhnian normal science, than one might otherwise suppose. In retrospect, revolutions disappear, for quite legitimate reasons, quite different from those discussed by Kuhn in section XI of *Structure*, "The Invisibility of Revolutions".

I have argued that putting AOE explicitly into scientific practice transforms science so that it seems to become close to normal science without revolutions as depicted by Kuhn. But does this really suffice to establish that science since Galileo, pursued in accordance with the edicts of AOE, would resemble normal science? It might be more appropriate to declare that, if science had been pursued in this way, Kuhn's distinction between normal and revolutionary science would no longer apply. There would be intermittent, dramatic changes of theory, but such changes would be anticipated, persistently worked for and progressively developed, and they would occur within a context of theoretical and empirical continuity and growth. Fundamental new theories in physics would not emerge, abruptly and inexplicably, out of the blue, in contexts of crises. There would be a rational, if non-mechanical and fallible, method for their discovery and development. They would emerge gradually as a result of work that would have some of the features of Kuhnian puzzle solving of normal science.

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Notes

[1] See Williams (1965, pp. 257-269).
[2] In his work after *Structure* on incommensurability, Kuhn continued to ignore Faraday's solution to the problem: see Kuhn (2000). In what follows I concentrate on what Kuhn says in *Structure*, because this seems to me to be so much more striking, important and influential than his later work on incommensurability.
[3] An assessment may, of course, be objective without being decisive.

[4] Kuhn (1970, p. 170). We can take it that Kuhn is not concerned, here, with the problem of verisimilitude – the problem of what it means to say of two false theories that one is closer to the truth than the other. His concern, rather, is that we cannot ever *know* of two paradigms that one is closer to the truth than the other – as the context makes clear.

[5] This is because physics is the fundamental natural science. A revolution in any other science – astronomy, chemistry, or geology – can exploit theoretical knowledge from a more fundamental science that persists throughout the revolution.

[6] Maxwell (1998, p. 181).

[7] See Maxwell (1998, chs. 3 and 4; 2004a, appendix, section 2; 2007, ch. 14, section 2).

[8] See Feynman (1965, ch. 25, pp. 10-11).

[9] Well known accounts of unification that fail to pass this hurdle are Friedman (1974), Kitcher (1989) and Watkins(1984, pp. 203-213). These and other accounts are decisively refuted by Maxwell (1998, pp. 56-68).

[10] For a very much more detailed account of theoretical unity along these lines, see Maxwell (1998, chs. 3 and 4). See also Maxwell (2004a, appendix, section 2; 2007, ch. 14, section 2; 2011, section 4).

[11] Strategies for concocting empirically more successful disunified rivals to accepted theories are discussed in Maxwell (1974; 1998, pp. 47-54; 2004a, pp. 10-11; 2013). These empirically more successful theories are disunified in the two or three most drastic of the eight kinds of disunity indicated in the previous section.

[12] For more detailed expositions of this argument see Maxwell (1998, chs. 1 and 2; 2011a; 2013).

[13] Many *imprecise* disunified theories will be true even in a universe that is perfectly physically comprehensible, in that the true physical "theory of everything", T, is unified. In such a universe, T implies any number of distinct, imprecise theories applicable to restricted ranges of phenomena. True disunified (but imprecise) theories can be arrived at by conjoining two or more such true distinct theories.

[14] Throughout, by "metaphysical" I mean "empirically untestable".

[15] AOE was first put forward in Maxwell (1974); see also Maxwell (1984, chs. 5 and 9; 1993a). A detailed exposition and defense is to be found in Maxwell (1998); see also Maxwell (2002; 2004a; 2005; 2006; 2010, ch. 5; 2011a; and especially 2007, ch. 12).

[16] See Maxwell (1998, pp. 17-19; 2004a, chs. 1 and 2).

[17] In terms of the account of theoretical unity of the previous section, we require that the true "theory of everything" is unified in all eight ways, with N = 1 in each case.

[18] This asserts that the universe is such that the true "theory of everything" can be formulated in terms of a unified Lagrangian (or Lagrangian density), with a single physical interpretation, and with a group structure which is such that it is not the product of sub-groups: see Maxwell (1998, pp. 88-89).

[19] Maxwell (1998, pp. 21-23; 2002, section 6). Others have argued that metaphysical presuppositions of science need to be acknowledged in order to solve the problem of induction: see, for example, Russell (1948, part VI) and Burks (1977, ch. 10). But these authors fail to stress, as AOE does, that precisely because these presuppositions are substantial, influential, and purely conjectural, they need to be subjected to sustained criticism and attempted improvement, a new methodology being required to do this.

[20] For details, see works referred to in note 18.

[21] See Maxwell (2004a, ch. 2). See also Maxwell (1993a, pp. 275-305; 1998, ch. 4).
[22] Maxwell (2007, ch. 12, section 6). See also Maxwell (1998, ch. 5; 2004a, appendix, section 6).
[23] See Maxwell (2004a, pp. 34-39 and 191-198). See also Maxwell (1993a, pp. 275-305; 1998, pp. 217-233).
[24] See Maxwell (1998, chs. 3 and 4; 2004a, appendix, section 2; 2007, ch. 14, section 2).
[25] See Maxwell (2004a, pp. 34-51).
[26] Granted standard empiricism, physics advancing from one false theory to another poses a serious threat to the view that physics makes theoretical progress across revolutions. That physics does seem to advance in this way has even been dubbed "the pessimistic induction": see Newton-Smith (1981, p. 41). Granted AOE, however, this is precisely the way theoretical physics must advance if it is to make progress, step by step, towards capturing physicalism in a true, unified, testable physical "theory of everything": see Maxwell (2007, ch. 14, section 5); see also Maxwell (1998, pp. 211-212).
[27] Misunderstood because it was not appreciated that the three of these four rules that concern simplicity or unity make metaphysical presuppositions – as Newton himself made clear: see Newton (1962, pp. 398-400).
[28] For more on this see Maxwell ((2007, ch. 14, section 5; 1998, pp. 211-212).
[29] Maxwell (1993a, pp. 275-305).
[30] Maxwell (1976; 1982; 1988; 1994; 1998, ch. 7; 2004b; 2011b).
[31] Maxwell (2004a, pp. 198-205; 2007, pp. 389-393).
[32] For an excellent non-technical account of superstring theory see Greene (1999).
[33] For some reservations concerning the claim that superstring theory puts AOE into practice, see Maxwell (2004a, pp. 36-37 and 197-198).
[34] Many physicists object to superstring theory on the grounds that it has made no successful empirical predictions and thus is not science at all – thereby revealing their allegiance to standard empiricism. For criticisms of superstring theory for its lack of empirical success, and on other grounds, see Greene (1999, ch. 9) and Smolin (2000, pp. 159-162).