The Need for a Revolution in the Philosophy of Science

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Abstract

There is a need to bring about a revolution in the philosophy of science, interpreted to be both the academic discipline, and the official view of the aims and methods of science upheld by the scientific community. At present both are dominated by the view that in science theories are chosen on the basis of empirical considerations alone, nothing being permanently accepted as a part of scientific knowledge independently of evidence. Biasing choice of theory in the direction of simplicity, unity or explanatory power does not permanently commit science to the thesis that nature is simple or unified. This current "paradigm" is, I argue, untenable. We need a new paradigm, which acknowledges that science makes a hierarchy of metaphysical assumptions concerning the comprehensibility and knowability of the universe, theories being chosen partly on the basis of compatibility with these assumptions. Eleven arguments are given for favouring this new "paradigm" over the current one.

Contents

1 Introduction

There is an urgent need for a revolution in the philosophy of science. By "the philosophy of science" I mean not only the academic discipline, but also the view about what the aims and methods of science are (and ought to be) upheld by the scientific community, influencing the way science is pursued, taught, funded, discussed, communicated to the public. I mean the view that is embedded, as it were, in the actual institutional structure of science, shaping the way science proceeds, as well as the academic discipline (at present linked only tenuously to science itself, and somewhat despised by many working scientists).

Philosophers of science are of course aware of many diverse "philosophies of science", views about what the aims and methods of science are, or ought to be. Logical positivism, inductivism, logical empiricism, hypothetico-deductivism, falsificationism, conventionalism, constructive empiricism, pragmatism, realism, induction-to-the-best-explanationism, the views of Kuhn, Lakatos and Feyerabend are just some of the available options (to say nothing of the views of sociologists and historians of science). However, these views, diverse as they may seem to be, have one basic thesis in common. I shall call this thesis *standard empiricism*.

2 The Old Paradigm: Standard Empiricism

Standard Empiricism (SE) asserts: In science, ideally, all claims to knowledge are to be assessed impartially with respect to the evidence, the simplicity, unity or explanatory power of theories being taken into account as well, *no thesis about the world being upheld* *permanently as a part of knowledge independently of evidence, let alone in violation of evidence*. Most, if not all, versions of SE stress that questions of simplicity, unity and explanatory power play a valid, important role in influencing choice of theory in science, in addition to considerations of empirical success - although some versions of SE give to simplicity and explanatory power much more important roles in science than other versions do. The decisive point that all versions of SE agree on is that no substantial thesis about the nature of the universe can be upheld as a part of scientific knowledge independently of empirical considerations, and certainly not in violation of empirical considerations. In so far as theory choice is biased in the direction of simplicity, unity or explanatoriness, this bias must not commit science to making the permanent assumption that nature herself is simple, unified or explainable.

This rather thin thesis is common ground for logical positivism, inductivism, logical empiricism, hypothetico-deductivism, falsificationism, conventionalism, constructive empiricism, pragmatism, realism, induction-to-the-best-explanationism, and the views of Kuhn and Lakatos.[1] There is a sense in which even Feyerabend, and even social constructivist and relativist sociologists and historians of science uphold SE as the best available ideal of scientific rationality. *If* science can be exhibited as rational, they hold (in effect), then this must be done in a way that is compatible with SE. The failure of science to live up to the rational ideal of SE is taken by them to demonstrate that science is not rational. That it is so taken demonstrates convincingly that they hold SE to be the only possible rational ideal for science (an ideal which cannot, it so happens, in their view, be met).

SE is more or less unthinkingly taken for granted by the vast majority of working scientists - so much so that it is rather rare to find the doctrine being explicitly formulated, let alone defended. Scattered throughout the writings of scientists one can, nevertheless, find affirmations of the view. Thus Planck once remarked "Experiments are the *only* means of knowledge at our disposal. The rest is poetry, imagination" (Atkins, 1983, p. xiv). Or, as Poincaré (1952, p. 140) put it "Experiment is the sole source of truth. It alone can teach us something new; it alone can give us certainty."[2]

Despite all this, SE can easily be shown to be untenable, in a quite decisive fashion. In the next section I spell out reasons for rejecting the prevailing "paradigm" of SE. In the section after I expound the new "paradigm" which, I hold, ought to replace SE. After some pertinent remarks about what it means to assert that the universe is "physically comprehensible", or has a "unified dynamic structure", I then give eleven reasons for rejecting SE and accepting in its stead the new paradigm of *aim-oriented empiricism*.

All this restates and, in some respects elaborates on arguments to be found in Maxwell (1998).[3]

3 Refutation of Standard Empiricism

Given any scientific theory, however well verified empirically, there will always be infinitely many rival theories which fit the available evidence just as well, but which make different predictions, in an arbitrary way, for phenomena not yet observed. Thus, given Newtonian theory (NT), one rival theory might assert: everything occurs as NT asserts up till midnight tonight when, abruptly, an inverse cube law of gravitation comes into operation. A second rival theory might assert: everything occurs as NT asserts, except for the case of any two solid gold spheres, each having a mass of a thousand tons, moving in otherwise empty space up to a mile apart, in which case the spheres attract each other by means of an inverse cube law of gravitation. A third rival asserts that everything occurs as NT asserts until three kilograms of gold dust and three kilograms of diamond dust are heated in a platinum flask to a temperature of 450^{o}C, in which case gravitation will instantly become a repulsive force everywhere. And so on. There is no limit to the number of rivals to NT that can be concocted in this way, each of which has all the predictive success of NT as far as observed phenomena are concerned but which makes different predictions for some as yet unobserved phenomena.[4] Such theories can even be concocted which are *more* empirically successful than NT, by arbitrarily modifying NT, in just this entirely *ad hoc* fashion, so that the theories yield correct predictions where NT does not, as in the case of the orbit of Mercury for example (which very slightly conflicts with NT).[5]

One can set out to refute these rival theories by making the relevant observations or experiments, but this needs an infinitely long time to complete as there are infinitely many rival theories to be refuted, each requiring a different refuting experiment. Thus, if science really did take seriously the idea that evidence alone decides what theories are to be accepted and rejected, scientific knowledge would be drowned in an infinite ocean of rival theories, all just as empirically successful as currently accepted theories, or actually even more successful empirically. Science would come to an end.[6]

Why does this not happen in scientific practice? Because, as most versions of SE stress, in practice *two* considerations govern acceptance and rejection of theories in science: (1) considerations of empirical success and failure; and (2) considerations that have to do with the simplicity, unity or explanatory power of the theories in question. In order to be accepted as a part of scientific knowledge, a theory must satisfy *both* considerations. It must be *both* empirically successful *and* simple, unified, or explanatory in character.[7]

Scientific theories that are accepted as a part of scientific knowledge, NT let us say, classical electromagnetism, quantum theory or Einstein's theories of special and general relativity, do (more or less adequately) satisfy *both* considerations. They are both amazingly successful in their capacity to predict observable phenomena, and astonishingly simple, unified, explanatory.

But the infinitely many empirically successful rivals to these accepted theories all *fail* to satisfy the second consideration. They may fit all available evidence just as well as Newton's theory does, or Einstein's theories do: but they fail, quite drastically, to be simple, unified, explanatory. For these rival theories all assert that, for some as yet unobserved kind of phenomenon, something entirely peculiar and arbitrary occurs. Where NT assures us that gravitation obeys an inverse square law and is attractive uniformly everywhere, for all time, the aberrant rivals to NT assert that for some specific kind of phenomenon or range of phenomena gravitation obeys a quite different law, an inverse cube law perhaps, or one that asserts that gravitation is a repulsive rather than attractive force.

Thus the infinitely many rivals to accepted physical theories are rejected out of hand, not on empirical grounds, but because they are grotesquely *ad hoc*, grotesquely lacking in simplicity, unity, explanatory power.

This, then, is why in practice science is not buried beneath an infinite mountain of rival theories, all of which fit all available evidence equally well, if not better. Almost all the rivals are horribly complex, disunified, non-explanatory.

But now comes the decisive point. In persistently rejecting infinitely many such empirically successful but grotesquely *ad hoc* theories, science in effect makes a big permanent assumption about the nature of the universe, to the effect that it is such that no grotesquely *ad hoc* theory is true, however empirically successful it may appear to be for a time.[8] Without some such big assumption as this, the empirical method of science collapses. Science is drowned in an infinite ocean of empirically successful *ad hoc* theories.

The orthodox conception of science is, in short, untenable.[9]

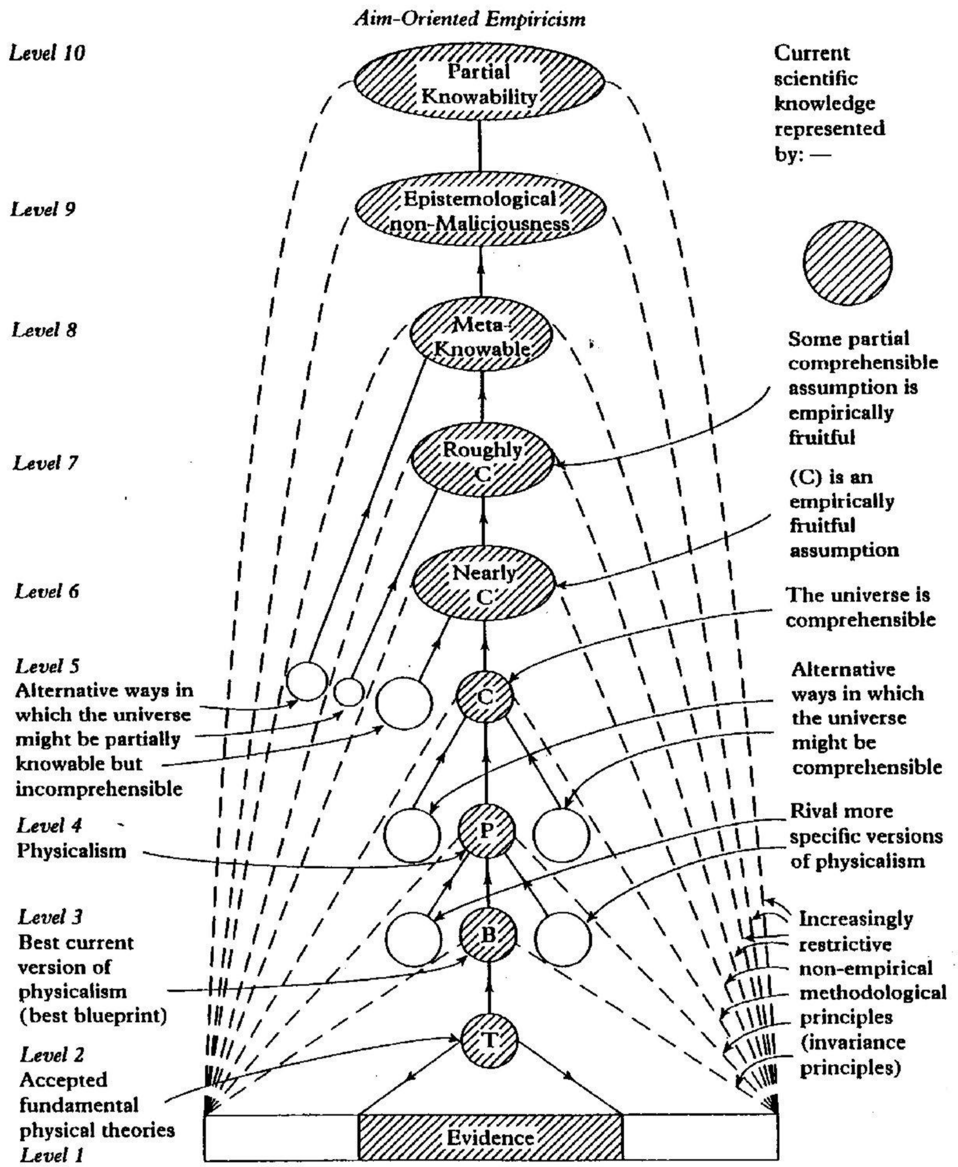
4 The New Paradigm: Aim-Oriented Empiricism

At once the question arises: Granted that science must make some kind of big assumption about the nature of the universe if it is to be possible at all, what precisely ought this assumption to be, and on what basis is it to be made? If science is to proceed successfully we must make an assumption that is near enough correct; and yet it is just here that we are most ignorant, and are almost bound to get things hopelessly wrong.

The solution to this fundamental epistemological problem of science (the very existence of which is denied by SE) is to construe science as adopting, as a part of scientific knowledge, a hierarchy of cosmological assumptions about the comprehensibility and knowability of the universe, these assumptions asserting less and less about the universe as one ascends the hierarchy, thus being more and more likely to be true: see diagram. Corresponding to these cosmological assumptions there are methodological rules (represented by dotted lines in the diagram) which govern acceptance of assumptions lower down in the hierarchy, and which, together with empirical considerations, govern acceptance and rejection of scientific theories. The top two assumptions, at levels 10 and 9, are such that accepting these assumptions as a part of scientific knowledge can only aid, and can never damage science (or the task of acquiring knowledge more generally) whatever the universe may be like. These are justifiably permanent items of scientific knowledge. Thus at level 10 we have the thesis that the universe is such that we can acquire some knowledge of our local circumstances: we are justified in accepting this as a permanent part of scientific knowledge. As we descend, from level 8 to level 3, the corresponding theses make increasingly substantial assertions about the nature of the universe: it becomes increasingly likely that these theses are false. At each level, from 8 to 3, we adopt that assumption which (a) is compatible with the assumption above it in the hierarchy (in so far as this is possible), and (b) holds out the greatest hope for the growth of empirical knowledge, and seems best to support the growth of such knowledge (at levels 1 and 2). If currently adopted cosmological assumptions, and associated methods, fail to support the growth of empirical knowledge, or fail to do so as apparently successfully as rival assumptions and methods, then assumptions and associated methods are changed, at whatever level appears to be required.[10] In this way we give ourselves the best hope of making progress, of acquiring authentic knowledge, while at the same time minimizing the chances of being taken up the garden path, or being stuck in a cul de sac. The hope is that as we increase our knowledge about the world we improve the cosmological assumptions implicit in our methods, and thus in turn improve our methods. As a result of improving our knowledge we improve our knowledge about how to improve knowledge. Science adapts its own nature to what it learns about the nature of the universe, thus increasing its capacity to make progress in knowledge about the world - the methodological key to the astonishing, accelerating progress of modern science.

This conception of science, postulating more or less specific evolving aims and methods for science within a framework of more general fixed aims and methods, I call *aim-oriented empiricism*.[11] It is a special case of a more general idea of *aim-oriented rationality*, according to which, whenever basic aims are problematic (as they usually are in science and in life) we need to display aims at distinct levels of specificity and generality, thus creating a framework within which we have the best chance of improving more or less specific, problematic aims-and-methods as we proceed, in the light of success and failure.[12]

According to aim-oriented empiricism (AOE), then, scientific knowledge can be represented (in a highly schematic and simplifying way) as being made up of the following ten levels: see diagram. At level 1, we have empirical data (low level experimental laws). At level 2, we have



Diagram

our best fundamental physical theories, currently general relativity and the so-called standard model. At level 3, we have the best, currently available specific idea as to how the universe is physically comprehensible. This asserts that everything is made of some specific kind of physical entity: corpuscle, point-particle, classical field, quantum field, convoluted space-time, string, or whatever. Because the thesis at this level is so specific, it is almost bound to be false (even if the universe is physically comprehensible in some way or other). Here, ideas evolve with evolving knowledge. At level 4 we have the much less specific thesis that the universe is *physically* comprehensible in some way or other (a thesis I shall call *physicalism*[13]); and at level 5 we have the even less specific thesis that the universe is *comprehensible* in some way or other, whether physically or in some other way. And as we ascend the hierarchy further, from level 6 to 8, the theses become increasingly unspecific, demanding in turn less and less comprehensibility or knowability of the universe, so that it becomes increasingly likely that these theses are true. Until, at levels 9 and 10 we arrive at theses so unspecific, so meagre, in what they require of the universe for it to be partially knowable, that it can only help and can never hinder the pursuit of knowledge, to accept these theses as a part of knowledge whatever the universe may be like. These theses are justifiably a permanent part of scientific knowledge.[14]

Ideally, the thesis at level 2 implies the one at level 3, and so on up the hierarchy until one reaches level 9 or 10. This is true for levels 4 to 9. It breaks down dramatically, however, when we come to levels 2, 3 and 4. Fundamental theories currently accepted in physics, general relativity and the standard model, clash, and thus fail to exemplify physicalism. Furthermore, instead of postulating just one kind of self-interacting entity, the standard model postulates three kinds of forces, and many different kinds of particles with diverse properties, such as mass, that are not theoretically determined. All this is a sign of our ignorance (just as failure of theories to predict phenomena successfully is). What drives physics forward is the attempt to solve the problems that arise as a result of clashes between levels 1, 2, 3 and 4. According to AOE, a basic task of theoretical physics will have been completed when a level 2 theory has been discovered which (a) in principle predicts all (physically) possible level 1 phenomena, and (b) implies a true level 3 thesis, which (c) exemplifies (and thus implies) the level 4 thesis of physical comprehensibility (physicalism).

5 Physical Comprehensibility

Two key theses in the hierarchy just indicated are the level 5 thesis that the universe is comprehensible, and the level 4 thesis that the universe is *physically* comprehensible. What do these assert?

The level 5 thesis of comprehensibility asserts that the universe is such that there is *something* (God, tribe of gods, cosmic goal, pattern of physical law, cosmic programme or whatever), which exists everywhere in an unchanging form and which, in some sense, determines or is responsible for everything that changes (all change and diversity in the world in principle being explicable and understandable in terms of the underlying unchanging *something*). A universe of this type deserves to be called "comprehensible" because it is such that everything that occurs, all change and diversity, can in principle be explained and understood as being the outcome of the operations of the one underlying *something*, present throughout all phenomena.

If the *something* that determines all change is what corresponds out there in the world to a unified pattern of physical law, then the universe is physically comprehensible. The universe is physically comprehensible, in other words, if some yet-to-be-discovered unified physical "theory of everything" or "final theory" is true.

Let us now consider, in a little more detail, what this means. (It is important to appreciate that, in what follows, I am indicating, informally, what it is that a specific *thesis* -

physicalism - asserts about the universe; I am not so much analyzing the meaning of "unity", as explicating what it is that physicalism asserts in asserting: the universe has a unified dynamic structure: for further details, see Maxwell, 1998, chs. 3 and 4.)

The basic idea is that the physically comprehensible universe consists of two aspects, U and V. U is an aspect of the cosmos that is present throughout all phenomena in an unchanging form, while V is that aspect that varies and changes from place to place and time to time. For physical comprehensibility we require first, that U is unified, and second, that U determines (perhaps probabilistically) the way in which V changes. But what does "unity" mean here? And what does it mean to assert that this unified aspect "determines" change?

As a first stab at answering these questions, let us consider an elementary example of a universe that is physically comprehensible in the specified sense. Consider a universe that consists only of the classical electromagnetic field in empty space (there being no charged particles to create, or be acted on, by the field).[15] This field is a physical entity that is spread out smoothly throughout space and time. It consists of two inter-related fields, the electric and magnetic fields. These inter-related fields together have two aspects, U and V.

The aspect that varies, V, (to take them in reverse order) consists of varying strengths or intensities of the electric field, **E**, and magnetic field, **B**.

The way in which **E** and **B** change is precisely determined by James Clerk Maxwell's equations of the electromagnetic field. That is, given the state of the field, the values of **E** and **B** at each point, at some instant (in some reference frame), this together with Maxwell's equations determines uniquely all subsequent (and previous) states of the field.

Maxwell's equations for the electromagnetic field in the vacuum assert:

$$(1)\quad \nabla\cdot\mathbf{E} = 0 \qquad\qquad (3)\quad \nabla\times\mathbf{E} = -\frac{1}{c}\frac{\partial\mathbf{B}}{\partial t}$$

$$(2)\quad \nabla\cdot\mathbf{B} = 0 \qquad\qquad (4)\quad \nabla\times\mathbf{B} = \frac{1}{c}\frac{\partial\mathbf{E}}{\partial t}$$

where c is the velocity of light.

Ordinarily (1) to (4) would be thought of as factual assertions. Here, they are to be reinterpreted as *analytic* statements, which tell us what it is for something to be the electromagnetic field. The empirical import of the theory is contained in a fifth postulate:
(5) The classical electromagnetic field, as characterized by (1) to (4), exists everywhere (and this is all that exists).

(1) to (4) are to be regarded as specifying a dispositional or necessitating physical property: if it exists everywhere then, necessarily, that which changes, values of the electric and magnetic fields, change in accordance with (1) to (4). *If* this necessitating property exists everywhere at an instant, then it, together with the instantaneous values of the electric and magnetic fields everywhere, determine all subsequent states of the field. In this sense the necessitating property (of being the classical electromagnetic field), specified by (1) to (4), itself does not change but determines how varying values of **E** and **B** do change.

Any fundamental physical theory that specifies how postulated fundamental physical entities evolve and interact can be interpreted in this "essentialistic" way. Instead of basic laws being interpreted as specifying regularities observed by the entities, they can be reinterpreted as specifying necessitating *properties* that the entities possess which determine (necessarily) how the entities evolve and interact. To say that the universe is physically comprehensible is to say that there exists an unchanging *something* (capable of being specified by a unified, essentialistically interpreted physical theory) which exists everywhere and which determines (perhaps probabilistically) the way in which everything that changes does change.[16]

What, it may be asked, leads one to hold that there is here one unified entity, the electromagnetic field, and not two entities, the electric field and the magnetic field? There are three points to note.

First, (3) and (4) specify how a magnetic field changing with respect to time creates a circulating electric field, and an electric field changing with respect to time creates a circulating magnetic field. The two fields, **E** and **B**, are not distinct; a change in the one creates the other. Interestingly enough, it is this interdependence of the electric and magnetic fields that is responsible for the other great feat of unification achieved by classical electrodynamics, namely the unification of light and electromagnetism. What these two equations imply is that once periodic changes in the electric or magnetic field have been set up they travel through space with the velocity of light, changing **E** producing a changing **B**, in turn producing a changing **E**, and so on. This, according to classical electrodynamics, is what light is.

The second point to note is the symmetry that exists between the way **E** affects **B**, and **B** affects **E**.

And the third point is that, given any specific space-time chunk of electromagnetic field evolving in accordance with the above four postulates, the way in which the field divides up into **E** and **B** depends on the choice of reference frame. The lengths and directions of vectors representing **E** and **B**, for the same chunk of space-time, differ with respect to two reference frames travelling at some uniform velocity with respect to each other. But, according to special relativity, nothing of absolute (or theoretically fundamental) significance can depend on the choice of reference frame. Any specific way of dividing up the electromagnetic field into **E** and **B** has as much absolute significance as a choice of velocity for some object. We cannot, in short, think of the electromagnetic field as being made up of two distinct fields, **E** and **B**, since any specific choice of **E** and **B** is arbitrary in that it amounts to an arbitrary choice of reference frame. There is thus the *one* entity, the electromagnetic field, made up of two symmetrically interdependent aspects, **E** and **B**.

There are two rather different kinds of unification in theoretical physics, which may be called "unification by annihilation" and "unification by synthesis". Unification by annihilation occurs when it emerges that, instead of there being a number of distinct kinds of entity (substance or phenomenon), E_0, E_1,...E_N, there is just the one kind of entity, E_0, the other entities, E_1,...E_N being no more than aspects of E_0. Unification by synthesis occurs when it emerges that apparently distinct kinds of entities, E_1,...E_N are really different aspects or facets of one common entity,
E_1 +...+ E_N.

Classical electrodynamics illustrates both kinds of unification. On the one hand (as I have just mentioned) classical electrodynamics depicts light as nothing more than wave-like changes in the electromagnetic field: light, as a phenomenon distinct from the electromagnetic field, is annihilated. On the other hand, the theory reveals that the electric and magnetic forces, which before the advent of the theory seemed to be two distinct forces, are two facets of one entity, the electromagnetic force or field: the electric and magnetic forces are unified by synthesis.

Great steps of unification by annihilation from the history of theoretical physics include: the discovery that the millions of different substances that exist are made up of different chemical combinations of under one hundred different elements; the discovery that these distinct elements are made up of atoms in turn made up of just three kinds of particle: the electron, proton and neutron; the discovery that gravitation is nothing more than the curvature of space-time; the discovery that the dozens of different hadronic particles revealed in the 1950's and 1960's are nothing more than relatively few different kinds of quarks interacting by means of the gluons associated with the strong force. Great steps of unification by synthesis include: the partial unification of space and time achieved by Einstein's special theory of relativity; the partial unification of energy and matter achieved, again, by special relativity, and enshrined in the most famous equation of modern physics: $E = mc^2$; the partial unification of the electromagnetic and so-called weak force achieved by Weinberg's and Salam's theory of quantum electroweak theory; the unification of the eight gluons of the strong force achieved by quantum chromodynamics.[17]

To sum up: the thesis that the universe is physically comprehensible asserts that it is made up of two aspects, U, a necessitating property which exists everywhere and does not change, and V, which is the aspect of the universe that is different, from place to place and time to time. Given U, and given V at an instant throughout the universe, all subsequent states of V are precisely determined (perhaps probabilistically). Furthermore, U is unified in the sense that, in so far as it consists of distinct parts or aspects, U_1, U_2,... U_N, these are unified by means of a symmetry in a way that is analogous to how the electric and magnetic fields are unified by the symmetry of special relativity (Lorentz invariance), in the manner indicated above.[18]

6 Eleven Reasons for Rejecting Standard Empiricism and Adopting Aim-Oriented Empiricism Instead

Arguments have already been given for rejecting SE and accepting AOE in its stead. Here are eleven further arguments.

(1) **Greater rigour**. An elementary requirement for intellectual rigour is that assumptions that are substantial, influential, problematic and implicit need to be made explicit, so that they can be criticized and, we may hope, improved. AOE puts this into practice, in that metaphysical assumptions, implicit in persistent preference in science for simple, unified or explanatory theories, are made explicit in such a way that they can be subjected to maximum critical appraisal, AOE providing a framework for their critical assessment. SE denies that any such metaphysical assumptions are implicit in the persistent scientific preference for simple theories. The attempt to do science in accordance with SE thus undermines scientific rigour, in that it leads science to violate the above elementary requirement for rigour. This greater rigour of AOE is no mere formal matter: it makes it possible for there to be a rational method of discovery in theoretical physics, something which SE does not permit, as we shall see (point (9) below).

(2) **Solution to Fundamental Epistemological Problem of Science**. Once it is recognized that persistent preference for simple or unifying theories in physics independent of empirical

considerations, or even against such considerations, means that science must make a big, permanent assumption about the nature of the universe, the fundamental question arises: What is this permanent assumption, and on what basis is it made? SE not only fails to solve the problem; it denies the very existence of the problem by denying that any such assumption *is* made by science in persistently preferring simple or unifying theories. AOE, by contrast, acknowledges the problem, stresses that this is the fundamental epistemological problem of science, and solves it by postulating a hierarchy of increasingly contentless assumptions concerning the comprehensibility and knowability of the universe, the top two being such that it can only benefit, and cannot harm, the search for knowledge whatever the universe is like. At any level in the hierarchy below the top two levels, that assumption is selected which (a) best accords with the assumption above, and (b) is the most fruitful, or promises to be the most fruitful, from the standpoint of the growth of empirical knowledge, at levels 1 and 2 (see diagram). Corresponding to these cosmological assumptions there are methodological rules (represented by dotted lines in diagram) which govern acceptance of assumptions lower down in the hierarchy, and which, together with empirical considerations, govern acceptance and rejection of scientific theories. This hierarchical structure of assumptions and associated methods is put forward as giving science the best hope of discovering and accepting those assumptions and methods which best promote the growth of empirical knowledge, at the same time giving science the best hope of discovering and rejecting assumptions that are blocking such growth. The hierarchical framework enables science to adapt its aims and methods to what it finds out about the universe, improving knowledge leading to improvement in knowledge about how to improve knowledge. All this is suppressed by SE.
(3) **The nature of simplicity**. SE cannot solve the problem of what the simplicity, unity or explanatory character of a theory *is*, a problem that even Einstein found baffling.[19] This problem arises because a simple theory can always be reformulated so that it becomes complex, and *vice versa*.[20] AOE solves the problem without difficulty. The totality of fundamental physical theory, T, is unified to the extent that its *content* exemplifies physicalism. The more the content of T departs from exemplifying physicalism, the more disunified T is.[21] Because what matters is content, not form, the way T is *formulated* is irrelevant to this way of assessing simplicity or unity.[22] SE cannot avail itself of this way of assessing unity because it involves acknowledging that physicalism is a basic tenet of scientific knowledge, something which SE denies. Within AOE, there is a second way in which the unity of T may be assessed: in terms of the extent to which the content of T exemplifies the best available more or less specific idea as to how the universe is physically comprehensible, at level 3. This second conception of simplicity or unity evolves with the evolution of level 3 ideas. As we improve our ideas about how the universe is unified, with the advance of knowledge in theoretical physics, so non-empirical methods for selecting theories on the basis of simplicity or unity improve as well. Thus current symmetry principles of modern physics, such as Lorentz invariance and gauge invariance, which guide acceptance of theory, are an advance over simplicity criteria upheld by Newton. This account of simplicity can be extended to individual theories in two ways. First, we may treat an individual theory as a candidate theory of everything. Second, given two individual theories, T_1 and T_2, and given the rest of fundamental theory, T, T_1 is simpler than T_2 iff $T + T_1$ is simpler than $T + T_2$, where the latter is assessed in one or other of the ways indicated above.[23]
(4) **The nature of scientific method**. Most versions of SE acknowledge (correctly) that two

considerations govern selection of theory in science, namely considerations that have to do with (a) evidence, and (b) simplicity. But because SE cannot solve the problem of what simplicity *is*, SE cannot, with any precision, specify what methods are involved when theories are selected on the basis of simplicity. Nor can SE do justice to the way in which the methods of physics evolve with evolving knowledge, especially methods that assert that acceptable theories must satisfy this or that *symmetry*. AOE, on the other hand, solves the problem of simplicity, and thus can specify precisely what methods are involved when theories are selected on the basis of simplicity. Furthermore, AOE can do justice to *evolving* criteria of simplicity (as we have just seen). According to AOE, the totality of fundamental physical theory, T, can be assessed with respect to how well its content exemplifies (i) the relatively fixed level 4 thesis of physicalism, or (ii) the evolving, best available level 3 thesis. Whereas (i) constitute fixed criteria of simplicity or unity (as long as physicalism is not modified), (ii) constitute evolving criteria, criteria of unity that improve with improving knowledge.

(5) **Justification of the methods of physics**. How are the methods, M, of science to be *justified*? That is, what justifies the claim that theories, T, accepted in accordance with methods, M, deserve to be regarded as constituting knowledge, in some sufficiently good sense of "knowledge"?

Attempts to solve this problem of justification, in essence the problem of induction, within the framework of SE, have all failed. This is not surprising: we have just seen that SE cannot even solve the preliminary problem of specifying what the methods, M, of science *are*. If M cannot be specified adequately, there is small hope that they can be justified. By contrast, AOE reveals that science provides its own justification for its choice of methods, as it proceeds.

Assumptions at the top two levels of the hierarchy are accepted because this can only help, and cannot harm, the search for knowledge whatever the universe may be like. Assumptions lower down in the hierarchy are accepted because these assumptions seem to promote the growth of empirical knowledge, at levels 1 and 2, better than any rival assumptions. This kind of ostensible fruitfulness for the (ostensible) growth of empirical knowledge, is the best indication we can have that the assumptions we are making are along the right lines. Displaying these assumptions in the form of a hierarchy, each assumption having decreasing content as we go up the hierarchy, gives science the best hope of discovering precisely where in the hierarchy an assumption is false, and needs to be modified or replaced.

Any claim to factual knowledge, however trivial, has a cosmological dimension. In claiming to know that I can walk across a room, I thereby claim that the entire cosmos is such that no vast explosion is occurring anywhere which will spread with near infinite speed to engulf the room before I have crossed it. The hierarchy of cosmological assumptions postulated and specified by AOE makes explicit for science a cosmological dimension that is implicit in all claims to factual knowledge.

The solution to the problem of induction must justify scientific knowledge *to the extent that this is possible*. AOE does just that. AOE does not, perhaps, enormously increase confidence in the correctness of science: but it does considerably increase our understanding of science. Some may reject the claim that AOE solves the problem of induction on the grounds that AOE does fail to increase confidence in science. But AOE cannot justifiably be found wanting for failing to provide what cannot be had. It is more rational to acknowledge the real fallibility of scientific knowledge, than to delude oneself into believing scientific knowledge is more secure than it is.[24] (Only those who suffer from this delusion will be unconvinced by the claim that AOE solves the problem of induction.)

(6) **Justification of preference for simple theories**. Not only does SE fail to say what simplicity is; it also fails to justify persistent preference for simple theories in science. AOE solves both problems. Persistent preference for simple, unifying or explanatory theories is justified because these are the theories which best exemplify the best available assumptions at levels 3 and 4. Science is justified in accepting these assumptions for reasons indicated in (5).

(7) **Evolving aims-and-methods**. A striking feature of physics is the way non-empirical methods, determining what theories will be accepted and rejected, have evolved from Newton's time to today. Newton, in his *Principia*, formulated four rules of reasoning, three of which are concerned with simplicity. Principles that have been proposed since his day include: invariance with respect to position, orientation, time, uniform velocity, charge conjugation, parity, time-reversal; principles of conservation of mass, momentum, angular momentum, energy, charge; Lorentz invariance; Mach's principle, the principle of equivalence; principles of gauge invariance, global and local; supersymmetry; duality principles; the principle that different kinds of particle should be reduced to one kind, and different kinds of force should be reduced to one kind; the principle that space-time on the one hand, and particles-and-forces on the other, should be unified. All of these principles can be interpreted as methodological rules which specify requirements theories must meet in order to be accepted. They can also be interpreted as physical principles, making substantial assertions about such things as space, time, matter, force. Some, such as conservation of mass, parity, and charge conjugation, have been shown to be false; others, such as Mach's principle, have never been generally accepted; still others, such as supersymmetry, remain speculative.

Principles such as these, which can be interpreted either as physical assertions or as methodological principles, which are made explicit, developed, revised and, on occasions, rejected or refuted, are hard to account for within the framework of SE. It is especially difficult, within the framework of SE, to account for principles which (a) have a quasi *a priori* role in specifying requirements theories must satisfy in order to be accepted, but which at the same time (b) make substantial *physical* assertions about the nature of the universe. AOE, on the other hand, predicts the existence of such principles, with just the features that have been indicated.

(8) **Verisimilitude**. The so-called problem of verisimilitude arises because physics proceeds from one false theory to another, thus rendering obscure what it can mean to say that science makes progress. Popper (1963, ch. 10 and Addenda) tried to solve this problem within the framework of SE but, as Miller (1974) and Tichy (1974) have shown, this attempted solution does not work. Not only does SE fail to justify the claim that theoretical physics makes progress; it fails even to say what progress in theoretical physics *means*.

AOE solves the problem without difficulty.

First, the fact that physics does proceed from one false theory to another, far from undermining physicalism, and hence AOE as well, is just the way theoretical physics must proceed, granted physicalism. For, granted physicalism, any theory, T*, which captures precisely how phenomena evolve in some restricted domain, must be generalizable to cover *all* phenomena. If T* cannot be so generalized then, granted physicalism, it cannot be precisely true. In so far as physics proceeds by developing theories which apply to restricted, but successively increasing, domains of phenomena, it is bound (granted physicalism) to proceed by proposing one false theory after another.

Second, AOE solves the problem of what it can *mean* to say that theories, T_0, ... T_N, get successively closer and closer to the true theory-of-everything, T, as follows. For this we require that T_N can be "approximately derived" from T (but not vice versa), T_{N-1} can be "approximately derived" from T_N (but not vice versa), and so on down to T_o being "approximately derivable" from T_1 (but not vice versa).

The key notion of "approximate derivation" can be indicated by considering a particular example, the "approximate derivation" of Kepler's law that planets move in ellipses around the sun (K) from Newtonian theory (NT).

The "derivation" is done in three steps. *First*, NT is restricted to N body systems interacting by gravitation alone within some definite volume, no two bodies being closer than some given distance r. *Second*, keeping the mass of one object constant, we consider the paths followed by the other bodies as their masses tend to zero. According to NT, in the limit, these paths are precisely those specified by K for planets. In this way we recover the *form* of K from NT. *Third*, we reinterpret this "derived" version of K so that it is now taken to apply to systems like that of our solar system. (It is of course this *third* step of reinterpretation that introduces error: mutual gravitational attraction between planets, and between planets and the sun, ensure that the paths of planets, with masses greater than zero, must diverge, however slightly, from precise Keplerian orbits.)

Quite generally, we can say that T_{r-1} is "approximately derivable" from T_r if and only if a theory empirically equivalent to T_{r-1} can be extracted from T_r by taking finitely many steps of the above type, involving (a) restricting the range of application of a theory, (b) allowing some combination of variables of a theory to tend to zero, and (c) reinterpreting a theory so that it applies to a wider range of phenomena.

This solution to the problem of what progress in theoretical physics *means* requires AOE to be presupposed; it does not work if SE is presupposed. This is because the solution requires one to assume (a) that the universe is such that a yet-to-be-discovered, true theory of everything, T, exists, and (b) current theoretical knowledge can be approximately derived from T. Both assumptions, (a) and (b), are justified granted AOE; neither assumption is justifiable granted SE.[25]

(9) **Discovery of New Fundamental Theories**. Given SE, the discovery of new fundamental physical theories that turn out, subsequently, to meet with great empirical success, is inexplicable. (One thinks here of Newton's discovery of his mechanical theory and theory of gravitation, Maxwell's discovery of classical electromagnetism, Einstein's discovery of the special and general theories of relativity, Bohr's discovery of "old" quantum theory, Heisenberg's and Schrödinger's discovery of "new" quantum theory, Dirac's discovery of the relativistic quantum theory of the electron and, in more recent times, the discovery of quantum electrodynamics, the electroweak theory, quantum chromodynamics, the standard model and string theory.) Granted that a new theory is required to explain a range of phenomena, there are, on the face of it, infinitely many possibilities. In the absence of rational guidance towards good conjectures, it would seem to be infinitely improbable that anyone should, in a finite time, be able to come up with a theory that successfully predicts

new phenomena. Not only does SE fail to provide such rational guidance; the only guidance that it is able to offer is of exactly the wrong kind, and would, if heeded, lead one persistently astray. Granted SE, the only way to proceed, so it would seem, is to generalize and adapt existing theories to form new theories applicable to the new range of phenomena. But new fundamental theories often do not emerge in this way. They almost invariably contradict earlier theories, and often have a conceptual structure that differs fundamentally from predecessor theories, most notable in the transition from Newton's to Einstein's theories of gravitation, and in the transition from classical to quantum theory. It is not surprising that those who defend versions of SE tend to deny that the discovery of new theories is any kind of rational process.[26] But if it is not rational, it becomes miraculous that good new theories are ever discovered. Scientific progress becomes, in other words, inexplicable.

AOE, by contrast, provides physics with a rational, if fallible and non-mechanical, method for the discovery of new fundamental physical theories. This method involves modifying the current best level 3 blueprint so that:

(a) the new blueprint exemplifies physicalism better than its predecessor;

(b) the new blueprint promises, when made sufficiently precise to become a testable theory, to unify clashes between predecessor theories;

(c) the new theory promises to exemplify the new blueprint better than the predecessor theories exemplify the predecessor blueprint.[27]

(a), (b) and (c) provide means for assessing how good an idea for a new theory is which do not involve empirical testing (which is brought in once the new theory has been formulated). The level 4 thesis of physicalism provides continuity between the state of knowledge before the discovery of the new theory, and the state of knowledge after this discovery. Modifying the current blueprint ensures that the new theory will be incompatible with its predecessors; it will postulate new kinds of entities, forces, space-time structure, and will exhibit new symmetries. In other words, because of the hierarchical structure of AOE, there is (across revolutions) both continuity (at level 4) and discontinuity (at levels 2 and 3), something that is not possible given SE. AOE provides physics with specific non-empirical tasks to perform, specific non-empirical problems to be solved, and non-empirical methods for the assessment of ideas for new theories, all of which adds up to a rational, if fallible, method of discovery. It all stems from recognizing that physicalism is a part of current scientific knowledge. The discovery of new fundamental physical theories ceases to be inexplicable. None of this is possible granted SE.[28]

The fact that AOE is able to provide a rational method of discovery, while SE is not, is due to the greater rigour of AOE (a point mentioned in (1) above). AOE has greater rigour than SE because AOE acknowledges, while SE denies, metaphysical assumptions implicit in persistent scientific preference for simple, explanatory theories. It is precisely the explicit acknowledgement of these metaphysical assumptions which makes the rational method of discovery of AOE possible.

(10) **Scientific practice**. Within the framework of SE, no one has succeeded in formulating a set of methodological rules which has won general acceptance as doing justice to scientific practice. Instead, there are sustained, fundamental disagreements about the nature of scientific method. Inductivists stress that laws and theories must be arrived at cautiously by generalizing from observed phenomena. Popper denies that this ever happens, and argues that scientists must boldly speculate and seek to refute their speculations experimentally.

Kuhn stresses that most of the time scientists protect the established theory or paradigm from refutation, normal science being devoted to showing that the established theory is able successfully to predict phenomena. Lakatos depicts science as consisting of competing research programmes, competing fragments of Kuhn's normal science. And Feyerabend concludes that none of the available views does justice to all good science, and that therefore the best policy is to hold that "anything goes". As Sokal and Bricmont (1998, p. 56) have recently put it "there does not exist (at least at present) a complete codification of scientific rationality, and we seriously doubt that one could ever exist".

By contrast, AOE is able to do justice to the range and richness of scientific practice, and is able, at the same time, to make clear why all SE attempts to depict scientific method fail. The fundamental natural science, theoretical physics, adopts a hierarchy of cosmological assumptions, to which correspond non-empirical methodological rules. As knowledge and understanding improve, cosmological assumptions and associated methods, lower down in the hierarchy, improve as well: more or less specific aims-and-methods improve within a framework of fixed aims-and-methods. Scientific method evolves with evolving knowledge. In order to do justice to this vital feature of scientific rationality, AOE characterizes scientific method at ten different levels. At level 1 there are observational and experimental methods, instruments and experimental techniques, associated with advances in empirical knowledge at level 1. At level 1, most strikingly, new knowledge can be used to acquire yet more new knowledge (as when, to give just one example of something that pervades the whole of science, Galileo uses the telescope to acquire astronomical knowledge). Here, too, knowledge generates knowledge. At level 2, new theoretical knowledge can be used to generate and assess further new knowledge, as when theory is used to predict new phenomena, and call experimental results into question which clash with accepted theory. At level 3, there are (non-empirical) methods used to develop and assess level 2 theory, that are associated with the best available level 3 blueprint. There are meta-methods associated with the level 4 thesis of physicalism which govern, in part, acceptance of level 3 blueprints and associated methods. There are meta-meta-methods (meta^2-methods) associated with the level 5 thesis of comprehensibility which govern, in part, acceptance of level 4 physicalism and associated meta-methods. And there are meta^3-methods, meta^4-methods, up to meta^7-methods, associated with cosmological theses at levels 6 to 10, none of which would need to be invoked explicitly in science unless current scientific knowledge turned out to be dramatically on the wrong lines. This meta-meta structure enables AOE to do justice to the radical evolution of scientific method, from the Presocratics and Aristotle, via Galileo, Newton, Darwin, Einstein down to scientists at work today. At some level, there are (or ought to be) common assumptions of comprehensibility or knowability, and common associated methods; at lower levels there are diverse more specific assumptions and associated methods. To discern the unity in the diversity, and the rationale for the diversity, it is essential to adopt the meta-meta, hierarchical viewpoint of AOE.

This is also able to do justice to the diversity of methods to be found in diverse sciences, without underlying unity and rationality being sacrificed. It is important to appreciate, first, that different branches of the natural sciences are not isolated from one another: they form an interconnected whole, from theoretical physics to molecular biology, neurology and the study of animal behaviour. Different branches of natural science, even different branches of a single science such as physics, chemistry or biology, have, at some level of specificity, different aims, and hence different methods. But at some level of generality all these branches of natural science have a common aim, and therefore common methods: to improve knowledge and understanding of the natural world. All put aim-oriented empiricism into practice, but because different scientific specialities have different specific aims, at the lower end of the hierarchy of methods different specialities have somewhat different methods, even though some more general methods are common to all the sciences. Furthermore, all natural sciences apart from theoretical physics presuppose and use results from other scientific specialities, as when chemistry presupposes atomic theory and quantum theory, and biology presupposes chemistry. The results of one science become a part of the presuppositions of another. This further enhances unity throughout diversity, and helps explain the need for diversity of method.

But in order to exhibit the rationality of the diversity of method in natural science, apparent in the evolution of methods of a single science, and apparent as one moves, at a given time, from one scientific speciality to another, it is essential to adopt the meta-meta, hierarchical standpoint of AOE, which alone enables one to depict methodological unity (high up in the hierarchy) throughout methodological diversity (low down in the hierarchy). SE, lacking this hierarchical structure, cannot begin to do justice to this key feature of scientific method, unity throughout diversity; nor can it begin to do justice to the rational *need* for this feature of scientific method.

Attempts to depict scientific method within the framework of SE are further cramped and distorted by the need to do justice to the point that, in physics, theories are only accepted if they accord sufficiently well with physicalism *without this being explicitly acknowledged*. As we saw above, SE must acknowledge that theory choice in physics is influenced by considerations of simplicity or explanatory capacity, but is unable to say what simplicity is, or why persistent preference for simplicity is justified.

There is a further, crucial point. Any new conception of science which improves our understanding of science ought to enable us to improve scientific practice. It would be very odd if our ability to do science well were wholly divorced from our understanding of what we are doing. A test for a new theory of scientific method ought to be, then, that it improves scientific practice, and does not merely accurately depict current practice. AOE passes this test. In providing a framework for the articulation and scrutiny of level 3 metaphysical blueprints, as an integral part of science itself, this providing a rational means for the development of new non-empirical methods, new symmetry principles, and new theories, AOE advocates, in effect, that current practice in theoretical physics be modified. It makes explicit what is at present only implicit. And more generally, in depicting scientific method in a hierarchical, meta-meta fashion, AOE has implications for method throughout the natural sciences, and not just for theoretical physics.

In case it should seem miraculous that science has made progress without AOE being generally understood and accepted, I should add that good science has always put something close to AOE into practice in an implicit, somewhat covert way, and it is this which has made progress possible. The attempt to do science in accordance with the edicts of SE has been sufficiently half-hearted, sufficiently hypocritical, to make progress possible. It is only the fully rigorous implementation of SE that would have brought science to a standstill.

(11) **Aim-oriented empiricism uniquely equipped to explain unprecedented success of modern science**. The hierarchical structure of cosmological theses of AOE is designed to

maximize the capacity of science to develop and choose those theses that best promote the growth of empirical knowledge, at levels 1 and 2. Any modification to the structure of AOE, which holds out a better hope of promoting such empirical growth, ought to be made. This means AOE is uniquely equipped to account for the rapid progress made by modern science. AOE is specifically designed to promote progress in scientific knowledge and understanding, however the universe may turn out to be. According to AOE, the key to scientific rationality is the positive feedback, engineered by AOE, that takes place between improving knowledge, and improving aims-and-methods, improving knowledge-about-how-to-improve-knowledge. No version of SE can incorporate this vital feature of AOE for maximizing the capacity of science to make progress.

7 Implications

What are the implications of pushing through the revolution that I have argued for, here, from SE to AOE?

First, there is a dramatic change in the whole relationship between science on the one hand, and metaphysics and philosophy on the other. Given SE, metaphysics and philosophy are excluded from science, in accordance with Popper's criterion of demarcation: metaphysical theories (such as that the universe is physically comprehensible), being experimentally untestable, are unscientific. But granted AOE it is clear that untestable metaphysical or philosophical ideas are absolutely basic to scientific knowledge. Metaphysical theses at levels 4 to 10 in the diagram are more firmly established than currently accepted theories of physics, such as general relativity or quantum theory. No longer can philosophy be a forbidden subject for undergraduate physicists: on the contrary, it must be an important part of the curriculum!

But before it becomes a standard part of science in this way, philosophy must itself undergo a revolution. According to AOE, the proper way to assess metaphysical theories about the nature of the universe is in terms of their fruitfulness for science. This is not the way philosophers tend to assess such theories at present.

A second implication of adopting the new conception of science is that fundamental problems in the philosophy of science, unsolved for centuries, become readily resolved, as we have seen in the previous section.

A third implication of adopting the new conception of science is that science acquires a rational, if fallible and non-mechanical method for the discovery of fundamental new theories. In the previous section I concentrated on the most problematic case of the discovery of new fundamental theories within physics. But AOE, in stressing the need to make problematic *aims* (and problematic *assumptions* implicit in aims) explicit, has fruitful implications for discovery throughout science.

A fourth implication of adopting the new conception of science is that there is a dramatic change in the whole conception of scientific method. Within the framework of AOE, philosophy of science, the study of aims and methods, becomes a vital part of science itself, being shaped by, *but also helping to shape*, the way science evolves. This new, hierarchical, aim-oriented conception of scientific method has far reaching implications for rationality in general. For it is not just science that has problematic aims; our aims in life, whether individual, institutional or social, are problematic. Above all, the aim of creating a better world is inherently and profoundly problematic. In these diverse fields, too, we need to put a generalized version of the progress-achieving methods of science into practice, designed to help us improve aims and methods as we proceed, as we live.[29]

But finally, perhaps the most dramatic consequence of adopting the new conception of science is the following. Granted SE, the thesis that the universe is physically comprehensible is definitely not a part of current scientific knowledge. But granted AOE, this thesis is a central component of current theoretical knowledge in science, more firmly established, as I have said, than any accepted physical theory. This is implicity, but not explicitly, recognized by physicists today when they concede that general relativity and the standard model, which do not form a unified theory, cannot therefore be correct. In holding that unity is a necessary condition for fundamental physical theory to be correct, physicists all but acknowledge that physicalism is a part of current knowledge.

They are prevented from acknowledging this explicitly by token allegiance to SE. The time has come to push through a revolution in our whole understanding of science. We need to reject standard empiricism in all its forms, and adopt aim-oriented empiricism in its stead as the new orthodoxy.

The argument of this paper reveals that there is a deep seated hypocrisy in humanity's understanding and use of science. In order to make sense of science we need to appreciate that science has discovered that the universe is physically comprehensible, in some way or other. This is however a discovery that is too disturbing for humanity readily to acknowledge. Scientists don't like to acknowledge the discovery, because it involves abandoning the idea that science differs radically from other enterprises - philosophy or religion - in that, in science, there are no permanent assumptions upheld independently of empirical considerations, everything being decided impartially on the basis of evidence. Non-scientists (and many scientists) don't like to acknowledge the discovery because it involves accepting that we - all that we are, experience, think, feel, do - are embedded in, and are a part of, a physical universe governed by a fixed pattern of physical law. We use the products of science, but shield our eyes from the disturbing sight that science appears to reveal about our nature, our life, all that we hold to be of most value.[30]

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Notes

1. For discussion of the claim that Kuhn and Lakatos defend versions of SE see Maxwell (1998), p. 40. Bayesianism might seem to reject SE, in acknowledging both prior and posteriori probabilities. But Bayesianism tries to conform to the spirit of SE as much as possible, by regarding prior probabilities as personal, subjective and non-rational, their role in theory choice being reduced as rapidly as possible by empirical testing: see Maxwell (1998), p. 44.
2. For more detailed discussion of the point that SE is widely taken for granted see Maxwell (1984), chs. 2 and 6, and Maxwell (1998), ch. 2.
3. See also Maxwell (1972), (1974), (1984) and (1993).
4. All the possible phenomena, predicted by any dynamical physical theory, T, may be represented by an imaginary "space", S, each point in S corresponding to a particular phenomenon, a particular kind of physical system evolving in time in the way predicted by T. In order to specify *ad hoc* rivals to T that fit all available evidence just as well as T does, all we need do is specify a region in S that consists of phenomena that have not been observed, and then replace the phenomenon predicted by T with anything we care to think of. Given

any T, there will always be infinitely many such *ad hoc* rivals to T.
5. For a more detailed discussion of empirically successful *ad hoc* rivals to accepted theories, see Maxwell (1998), pp. 51-54.
6. This argument generalizes Goodman's (1954) argument concerning green and grue. Two rival theories considered by Goodman are "All emeralds are green" and "All emeralds are grue", where an emerald is grue if it is examined before time t and green or not examined before t and blue. Before time t, available evidence appears to support both theories equally well. The argument given here improves on Goodman's argument, in my view, in that it makes closer contact with science. *Ad hoc* theories, admittedly not quite as bizarre as the rivals to NT that I have indicated, can be a serious issue in science. It is important to appreciate that the problem of why such theories deserve to be rejected is a serious problem for science, and not merely a weird philosophical puzzle.
7. Induction-to-the-best-explanation gets this part right!
8. This is where "induction-to-the-best-explanation" goes wrong. It tries to make persistent preference for explanatory theories in science, independent of empirical considerations, something that is compatible with SE.
9. For a much more detailed presentation of this refutation of SE see Maxwell (1998), ch. 2.
10. It may be asked: But how can acceptance of a level 3 assumption both influence, and be influenced by, acceptance of level 2 theories? The answer is that, at any stage in the development of science, rival level 3 ideas can contend; these lead to rival research programmes (Lakatos, 1970), which can be assessed with respect to their relative empirical growth. Within a research programme, theories are rejected that clash with the basic level 3 idea; this idea is rejected if a rival research programme meets with greater empirical success over a period of time. Level 3 ideas are also assessed in terms of how well they exemplify the accepted level 4 thesis. (But this too is open to revision, if such a revision leads to a more empirically progressive research programme.)

Suppose that B_1 is accepted at level 3, at a certain stage in the development of science. Suppose, now, that successive, increasingly empirically successful (level 2) theories, T_1, T_2, T_3 are put forward which clash with B_1, but exemplify beautifully a different level 3 thesis B_2, so that the B_2 research programme achieves greater empirical success than the B_1 programme does. Suppose further that B_1 and B_2 exemplify the level 4 thesis (of physical comprehensibility) equally well. This justifies accepting B_2 and rejecting B_1 (on quasi-empirical grounds). If B_2 exemplifies the level 4 thesis (of physical comprehensibility) better than B_1 does, all the more reason to accept B_2 in preference to B_1. For further details of how metaphysical theses are to be selected, at various levels, partly on the basis of the empirical success and failure of rival research programmes, within the framework of aim-oriented empiricism, see Maxwell (1998), chs. 4 and 5.
11. Corresponding to each cosmological thesis, at level 3 to 10, there is a more or less problematic *aim* for theoretical physics: to specify that cosmological thesis as a true, precise, testable, experimentally confirmed "theory of everything". Aims corresponding to levels 9 and 10 are relatively unproblematic: circumstances will never arise such that it would serve the interests of acquiring knowledge to revise these aims. As one descends the hierarchy of cosmological assumptions, the corresponding aims become increasingly problematic, increasingly likely to be unrealizable, just because the corresponding assumption becomes

increasingly likely to be false. Whereas upper level aims and methods will not need revision, lower level aims and methods, especially those corresponding to level 3, will need to be revised as science advances. Thus lower level aims and methods evolve within the fixed framework of upper aims and methods.

12. For the generalization of aim-oriented empiricism to form aim-oriented rationality see Maxwell (1984), (1992), (2000), (2002).

13. Smart (1963) has used the term 'physicalism' to stand for the view that the world is made up entirely of physical entities of the kind postulated by fundamental physical theories - electrons, quarks and so on. As I am using the term, 'physicalism' stands for the much stronger doctrine that the universe is physically comprehensible, that it is such that some yet-to-be-discovered, unified "theory of everything" is true.

14. For further details see Maxwell (1998), ch. 1.

15. This toy example of a physically comprehensible universe does not exhibit full dynamic unity, in the sense indicated below, in that the field and space-time are not unified to form *one* entity.

16. For further details concerning this essentialistic approach to physics, and the hypothetical existence of necessary connections between successive events, see: Maxwell: (1968); (1993), Part 2, pp. 81-101; (1998), pp. 141-155.

17. For a slightly more detailed, informal account of these great feats of unification see Maxwell (1998), pp. 123-140.

18. Additional examples of the way unity is achieved by symmetry are: the (partial) unity of the electroweak theory, due to the fact that the theory exhibits the local gauge symmetry of U(1)XSU(2); and the unity of chromodynamics due to the fact that the theory exhibits the local gauge symmetry of SU(3). For full unity, we require that the symmetry group is not a direct product of subgroups. The symmetry group of the electroweak theory *is* a direct product of subgroups; hence the theory does not fully unify the electromagnetic and weak forces. It may be that the symmetry is spontaneously broken, as in the case of electroweak theory. Within modern theoretical physics, the hunt for the precise nature of U is largely (but not entirely) the hunt for the symmetry group that bestows unity on U. For an informal exposition of these matters for non-experts, and for further literature on the subject, and for a more detailed discussion of the meaningfulness of physicalism, see Maxwell (1998), especially chs. 3 and 4, and the appendix.

19. See Einstein (1949), p. 23. For discussion, see Maxwell (1998), pp. 105-106.

20. For accounts of failed attempts at solving the problem of simplicity within the framework of SE, see Salmon (1989), Maxwell (1998), pp. 56-68.

21. Dynamical theories are partially ordered with respect to the extent that they exemplify physicalism, with respect to their degree of unity, in other words. For further details see Maxwell (1998), ch. 4.

22. It may be objected that this proposed solution to the problem of simplicity is circular: the unity of level 2 theory is explicated in terms of the unity of level 4 physicalism. But this objection is not valid. In order to solve the problem, it is not necessary to explicate what "simplicity" or "unity" mean; rather, what needs to be done is to show how theories can be partially ordered with respect to "simplicity" or "unity" in a way that does not depend on formulation. This is achieved by partially ordering theories in terms of how well their content

exemplifies the content of physicalism, so that, roughly, the more the content of a theory violates the symmetries associated with the content of physicalism, the less unity it has. As long as physicalism is a meaningful thesis, and provides a formulation-independent way of partially ordering theories in the way indicated, this suffices to solve the problem. That physicalism embodies intuitive ideas of "unity" is a bonus. For a more detailed rebuttal of this objection, see Maxwell (1998), pp. 118-123.

23. For a very much more detailed exposition of this solution of the problem of simplicity, together with an account of the way in which great unifying theories of physics illustrate the solution, see Maxwell (1998), chs. 3 and 4.

24. How secure one judges theoretical scientific knowledge to be ought to depend on how secure one judges the theses of comprehensibility, and physical comprehensibility, to be. If these theses are held to be no more than wild metaphysical speculations, theoretical scientific knowledge ought to be held to be similarly speculative. But if it is legitimate to hold that these theses are reasonably secure items of scientific and common sense knowledge, then theoretical scientific knowledge may legitimately be held to be reasonably secure also.

25. It may be objected that if T is assumed to be the true *unified* theory of everything, no meaning can be given to the idea that theoretical physics is making progress, by means of a succession of false theories, to a more or less *disunified* theory of everything. But T does not need to be assumed to be unified; all that is required is that T is such that the notion of "partial derivation" from T makes sense. For further discussion of the inability of SE to solve the problem of verisimilitude, and the ability to AOE to solve the problem, see Maxwell (1998), 70-72, 211-217 and 226-227.

26. Reichenbach (1938, pp. 381-383), Popper (1959, p. 31), Kuhn (1970) and Lakatos (1970) all, in effect, deny that discovery of new fundamental physical theories, new "paradigms" or "hard cores", is rational.

27. Kuhn (1970) gives a brilliant description of the way, during a scientific revolution, competing arguments for the rival paradigms are circular, each presupposing what is being argued for. But this can be seen to be a direct consequence of trying to do science in accordance with SE. This banishes explicit discussion of theses at levels 3 and 4; no wonder conservatives assess the new theory in terms of the old blueprint, and are unimpressed by the revolutionary assessment of the new theory in terms of the new blueprint. (The Gestalt switch, described by Kuhn, can be pin-pointed as the act of abandoning the old blueprint and adopting the new one.) Accept AOE, however, and it becomes possible for both parties, not only to acknowledge both old and new blueprints (distinct from corresponding theories), but also to discuss the adequacy of the new blueprint from the common standpoint of how adequately it exemplifies physicalism, which ought to be accepted by both parties. The irrationality of revolutions, depicted by Kuhn, disappears.

28. For further discussion of the method of discovery provided by AOE see Maxwell (1974), Part II; (1993), Part III; and (1998), 159-163 and 219-223.

29. See Maxwell (1984), (1992), (2000), (2002). The argument, as developed in these works, has far more radical implications for the nature of social inquiry than for the nature of natural science. Social inquiry becomes social *methodology* or social *philosophy*, rather than, primarily, social *science*. The philosophy of science, and the sociology of science, at present at odds with one another, become one and the same discipline: see Maxwell (1984), ch. 5,

especially pp. 107-117. See also Maxwell (2002).
30. For a discussion of the problem of how what is of value about our human world can be accommodated within a physically comprehensible universe see Maxwell (2001).