SIMPLICITY[1]

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ABSTRACT

There are two problems of simplicity. What does it mean to characterize a scientific theory as simple, unified or explanatory in view of the fact that a simple theory can always be made complex (and vice versa) by a change of terminology? How is preference in science for simple theories to be justified? In this paper I put forward a proposal as to how the first problem is to be solved. The more nearly the totality of fundamental physical theory exemplifies the metaphysical thesis that the universe has a unified dynamic structure, so the simpler that totality of theory is. What matters is content, not form. This proposed solution may appear to be circular, but I argue that it is not. Towards the end of the paper I make a few remarks about the second, justificational problem of simplicity.

1 SIMPLICITY PROBLEMS

Two basic problems arise in connection with the simplicity (or complexity) of scientific theories.

(1) What IS simplicity?

(2) What is the justification for the persistence preference for simple theories in science?

In this paper I set out to solve problem (1); towards the end I will make a few remarks about problem (2).

"Simplicity"[2] in the present context apparently means the simplicity of the form of a law or theory - the extent to which the functions, the equations, of the theory are simple. But it also means the extent to which a theory is non-ad hoc, or explanatory, or elegant, or unified, or conceptually coherent, or possessing what Einstein called inner perfection or, in other contexts, beauty, comprehensibility or intelligibility.

In judging some theories to be "simple" and others to be "complex", physicists may mean only that some theories have equations much easier to solve than those of other theories. This pragmatic meaning of simplicity is, of course, of immense importance in physics - especially in less fundamental, more phenomenological parts of physics, where the aim is primarily the instrumentalist one of predicting phenomena as easily and accurately as possible. There is, however, no particular reason why simplicity, in this pragmatic sense, should be an indication of truth. Here our concern is only with simplicity insofar as this is (or is taken to be) an indication of truth. The assumption is that a theory, in order to be accepted as a contribution to scientific knowledge, must be (a) sufficiently empirically successful, and (b) sufficiently "simple". This paper is concerned with non-empirical criteria for acceptance, (b).

The problem of what simplicity is breaks up into the following subordinate problems.

(i) The terminological problem: whether a theory is simple or complex appears to depend on how the theory is formulated, the terminology or concepts used to formulate it. But how can such a terminology-dependent notion of simplicity have any significant methodological or epistemological role in science? What determines the "correct" terminology, in terms of which theories are to be formulated so that their simplicity may be appraised? How can there possibly be any such thing as the "correct" terminology? If there is not, does not the whole notion of simplicity of theories collapse? On the one hand, the simplicity or complexity of a theory must, it seems, depend on the terminology used to formulate it, but on the other hand, this cannot, it seems, be the case if the simplicity is to be significant as an indication of truth.

Richard Feynman[3] has provided the following amusing illustration of the terminological problem. Consider an appallingly complex universe governed by a million million quite different, distinct laws. Even in such a universe, the true theory of everything" can be expressed in the dazzlingly simple, unified form: $A = 0$. Suppose the million million distinct laws of the universe are: (1) $F = ma$; (2) $F = Gm_1m_2/d^2$; etc. Let $A_1 = (F - ma)^2$, $A_2 = (F - Gm_1m_2/d^2)^2$, etc., for all million million distinct laws. Let $A = A_1+A_2+ ...+A_N$, where N is a million million. The true "theory of everything" of this universe can now be formulated as: $A = 0$. (This is true if and only if each $A_r = 0$.)

(ii) The problem of changing notions of simplicity. As science develops, what simplicity means changes. What it meant to Newton is different from what it would have meant to a nineteenth century physicist, which is different again from what it would mean to a late 20th century physicist. How can justice be done to the changing nature of simplicity (and to variability from one discipline to another)?

(iii) The problem of the multi-faceted nature of simplicity. "Simple" is the generic term that philosophers of science tend to use for a whole family of notions that scientists appeal to in assessing the non-empirical merits of theories, as I have indicated above. An acceptable theory of simplicity ought to pick out just one concept as fundamental, but at the same time do justice to the role that the other concepts appear to have in assessing theories in physics.

(iv) The problem of ambiguity. An indication of the complexity of the notion of simplicity in physics is given by the fact that one theory may be, in an obvious sense, much more complex than another, and yet, at the same, in a much more important sense, much simpler. The classic case of this ambiguity of simplicity is provided by a comparison of Newton's and Einstein's theories of gravity. In one obvious sense, Newton's theory is much simpler than Einstein's; in another sense, Einstein's theory is the simpler. An adequate theory of simplicity must resolve this puzzling state of affairs.

(v) The problem of doing justice to the intuition of physicists. Physicists are by no means unanimous in their judgements concerning the simplicity of theories, but there is a considerable level of agreement. An acceptable theory of simplicity must do justice to such agreed intuitions.

(vi) The problem of improving on the intuitions of physicists. An acceptable theory of simplicity ought to be able to improve on the intuitions of physicists, if it provides a genuine clarification of the nature of simplicity.

The first of these problems, the terminological problem, is by far the most serious. It has the form of a paradox. The degree of simplicity of a theory both must, and cannot possibly, depend on terminology.

2 ATTEMPTS AT SOLUTIONS

Kepler, Galileo, Newton, and almost every notable theoretical physicist since have recognized that simplicity plays an important role when it comes to deciding what theories should be accepted in physical science. But no one has been able to give a satisfactory account of what simplicity is. Simplicity is, indeed, widely recognized as posing a fundamental unsolved problem in the philosophy of science. Thus Weyl struggled with the problem and remarked "the problem of simplicity is of central importance for the epistemology of the natural sciences".[4] Einstein admitted that he did not know how to solve the problem of specifying what simplicity, or "inner perfection" as he called it, is.[5]

Others have proposed solutions. Jeffreys and Wrinch, long ago, suggested that simplicity could be identified with paucity of freely adjustable constants in an equation.[6] There is clearly something right about this proposal; the so-called "standard model" (SM) of contemporary physics (quantum electroweak theory, quantum chromodynamics, plus fundamental particle theory) is generally regarded as unsatisfactory because there are too many constants undetermined by theory (such as masses of the particles). Nevertheless the proposal does not solve the problem: number of constants is highly dependent on how a theory is formulated. Popper proposed that simplicity be identified with falsifiability;[7] but this does not work. A simple theory can have its falsifiability increased with the addition of independently testable postulates, an ad hoc adjunct to the initial theory; this would decrease the simplicity of the theory. More recently, Friedman, Kitcher and Watkins have attempted to identify simplicity with structural, formal or axiomatic features of theories.[8] These attempts all fail to solve the terminology problem because the specified features of theories are all highly terminology-dependent.[9]

3 AIM-ORIENTED EMPIRICISM

In order to solve the problems of simplicity, it is necessary and sufficient to adopt a conception of science that I call "aim-oriented empiricism" (AOE).[10] In this section I expound AOE; in the next I show how AOE solves simplicity problems.

According to AOE, we need to display knowledge in physics at the following ten levels.

Level 1: P_1. Empirical data (low level observational and experimental laws).

Level 2: P_2. Accepted fundamental physical theories, such as general relativity (GR) and quantum theory (QT).

Level 3: P_3. Best available more or less precise version of physicalism (see below) which is at present, I suggest, a doctrine that may be called Lagrangianism. According to Lagrangianism, the universe is such that all phenomena evolve in accordance with Hamilton's principle of least action, formulated in terms of some unified Lagrangian (or Lagrangian density), L. We require, here, that L is not the sum of two or more distinct Lagrangians, with distinct physical interpretations and symmetries, for example one for the electroweak force, one for the strong force, and one for gravitation, as at present; L must have a single physical interpretation, and its symmetries must have an appropriate group structure. We require, in addition, that current quantum field theories and GR emerge when appropriate limits are taken.

Level 4: P_4. Physical Comprehensibility or Physicalism. The universe is such that there is an impersonal, unchanging, knowable *something*, U, that exists everywhere, and determines (deterministically or probabilistically), how that which varies, V, does vary, from instant to instant. (Given U, and given the value of V at an instant throughout the universe, all subsequent values of V are determined uniquely, given determinism, or determined probabilistically, given probabilism.) In other words, the universe is such that some as-yet-to-be-formulated, unified theory of everything is true (specifying the nature of U and V), which might, but need not be, formulatable in terms of a Lagrangian and Hamilton's principle.
Level 5: P_5. Comprehensibility. The universe is such that there is a knowable *something* (God, tribe of gods, cosmic goal, unified pattern of physical law, cosmic programme or whatever) 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*.[11]
Level 6: P_6. Near Comprehensibility. The universe is sufficiently approximately comprehensible for the assumption of perfect comprehensibility to be more fruitful than any comparable assumption from the standpoint of improving knowledge.
Level 7: P_7. Rough Comprehensibility. The universe is such that some assumption of partial comprehensibility is fruitful from the standpoint of improving knowledge.
Level 8: P_8. Meta-Knowability. The universe is such that there is some discoverable[12] assumption that can be made about the nature of the universe which aids, and does not hinder, the growth of knowledge.
Level 9: P_9. Epistemological Non-Maliciousness. The universe is such that it does not exhibit comprehensibility, meta-knowability, or even mere partial knowability more generally, in our immediate environment only. However radically different phenomena may be elsewhere in the universe, the general nature of all such phenomena is such that it can in principle be discovered by us by developing knowledge acquired in our immediate environment. If aberrant phenomena occur, their occurrence is discoverable by us in our immediate environment.
Level 10: P_{10}. Partial Knowability. We possess some factual knowledge of our immediate environment, and some capacity to improve this knowledge, sufficient at least to make partially successful action in the world possible; the universe is such that the possession and acquisition of such knowledge is possible.[13]

A few words of clarification concerning the principles at levels 3 to 10. They are to be understood in such a way that P_r implies P_{r+1} for r = 3,...9, but not vice versa.[14] P_3 has the most content, and is therefore the most likely to be false, while P_{10} has the least content, and is thus the least likely to be false. It is more than likely that P_3 *is* false, progress in theoretical physics requiring that a revised version of this "level 3" principle be accepted (recent developments in quantum gravity, having to do with "duality", suggesting that this may well be the case). It is less likely that P_4 is false, less likely that progress in theoretical physics will require this level 4 principle be revised, although this is still a possibility. And as we ascend, from r = 3 to r = 8, the corresponding principles become increasingly contentless, and increasingly unlikely to require revision, although the possibility always exists. The cosmological theses, P_3, ... P_8, have the form that they do have in part because of the way that natural science in general, and theoretical physics in particular, have developed during the last four hundred (or two thousand) years. A radically different history, with a radically different outcome, would result in a different set of principles up to some value of r less than 9, the more radically different so the greater the value of r.

P_3 requires, perhaps, a few words of explication. All fundamental, dynamical theories accepted so far in physics, from Newtonian theory, (NT), classical electrodynamics, to GR, non-relativistic QT, quantum electrodynamics, quantum electroweak-dynamics, quantum chromodynamics, and SM, can be formulated in terms of a Lagrangian and Hamilton's principle of least action. In the case of NT, this takes the following form. Given any system, we can specify its kinetic energy, KE (energy of motion), and its potential energy, PE (energy of position due to forces), at each instant. This enables us to define the Lagrangian, L, equal at each instant to KE - PE. Hamilton's principle states that, given two instants, t1 and t2, the system evolves in such a way that the sum of instantaneous values of KE - PE, for times between t1 and t2, is a minimum value (or, more accurately, a stationary value, so that it is unaffected to first order by infinitesimal variations in the way the system evolves). From the Lagrangian for NT (a function of the positions and momenta of particles) and Hamilton's principle of least action, we can derive NT in the form familiar from elementary textbooks.

It is this way of formulating NT, in terms of a Lagrangian, L, and Hamilton's principle, that can be generalized to apply to all accepted fundamental theories in physics. Thus P_3 asserts that the universe is such that a true, unified theory of everything, T, can be formulated, T being such that it can be given a Lagrangian formulation in the way indicated.[15]

P_4 asserts, a little more modestly, that the universe is such that some kind of true, unified theory of everything, T, can be formulated, T not necessarily being such that it can be given a Lagrangian formulation. P5 asserts, more modestly still, that the universe is comprehensible *in some way or other*, but not necessarily physically comprehensible. P_6 asserts, even more modestly, that the universe is sufficiently nearly comprehensible for the assumption that it is perfectly comprehensible to be more fruitful from the standpoint of the growth of knowledge than any comparable rival assumption, relative to our existing knowledge. P_7 asserts, more modestly still, that the universe is such that some assumption of partial comprehensibility is more fruitful than any rival, comparable assumption. It might be the case, for example, that the universe is such that there are *three* fundamental forces, theoretical revolutions involving the development of theories that progressively specify the nature of these three forces more and more precisely. In this case, the assumption that there are three distinct forces would be more helpful than that there is just ONE fundamental force (required if the universe is to be perfectly comprehensible physically). Alternatively, it might be the case that the universe is such that, progress in theoretical physics requires there to be a series of theoretical revolutions, there being, after each revolution, one more force: in this case, the assumption that the universe is such that the number of distinct forces goes up by one after each revolution would be more helpful for the growth of knowledge than the assumption that there is just one fundamental force. P8, even more modestly, asserts merely that the universe is such that existing methods for improving knowledge can be improved. These methods might involve consulting oracles, prophets or dreams; they need not involve developing explanatory theories and testing them against experience. P_9 asserts, still more modestly, that the universe is such that local knowledge can be developed so that it applies non-locally;[16] and P_{10} asserts, even more modestly, that the universe is such that some factual knowledge of our immediate environment exists and can be acquired.

4 HOW AOE SOLVES THE PROBLEM OF WHAT SIMPLICITY IS

In order to solve the above five problems concerning what simplicity *is*, we shall need to appeal only to levels 2 to 4 of AOE.

According to AOE, simplicity, in the context of theoretical physics, applies to the totality of fundamental physical theories, T. To say that T is simple is to say that T is a precise version of the vague, level 4 thesis of physicalism. The key notion is thus *unity* – unity of the *content* of the totality of fundamental dynamical theory. Given two rival total theories, T_n and T_{n+1}, T_{n+1} is simpler than T_n if and only if T_{n+1} exemplifies physicalism better than T_n does. In other words, if Tn is more disunified than Tn+1 (in one or more of the eight different ways discussed below) then Tn is less simple.

This account of simplicity can be extended to individual theories in two different ways. An individual theory, T*, is "simpler" than a rival, T**, if Tm+T* exemplifies physicalism better than Tm+T** does, where Tm is the conjunction of all other current, accepted, fundamental theories. We can also, however, treat an individual theory as if it is a "theory of everything", ignoring all phenomena which lie outside the domain of the theory. Given two rival individual theories, T1 and T2, we can regard them as rival "theories of everything" and consider their relative simplicity, i.e. unity, i.e. their success, when so regarded, of being precise versions of physicalism.

Furthermore, this account can be straightforwardly extended to do justice to the point that notions of simplicity evolve with evolving knowledge. Theoretical physics does not just, in practice, presuppose physicalism; at any given time it presupposes some more precise version of physicalism, some level 3 blueprint, Bn, which is almost certainly false and will need to be changed so that it subsequently becomes Bn+1, which in turn becomes Bn+2, and so on. Bn might be the blueprint that the world is made up of small, rigid, spherical corpuscles with mass that interact only by contact, and Bn+1 might be the Boscovichean blueprint that the world consists of point-particles with mass that interact by means of a rigid, spherically symmetrical field of force that varies with distance from each point-particle. Other blueprints important in the history of physics are: the aether blueprint of 19th century physics, the aether being an elastic medium filling space which transmits gravitational and electromagnetic forces and light, and in which matter is embedded; the unified field/particle blueprint, charged particles being both sources of the field and acted on by the field; the unified self-interacting field, particles and matter being merely intense regions of the field; the geometrical blueprint, particles and forces being nothing more than topological or geometrical features of space-time; the quantum field blueprint of modern physics, particles being excitations of the field; the Lagrangian blueprint, discussed above; the superstring blueprint, according to which particles have the form of minute strings embedded in space-time of ten or twentysix dimensions, those in excess of four being curled up into a minute size.

In accepting a blueprint B, we accept that the fundamental physical entities and force(s) are as specified by B; we accept a set of invariance or symmetry principles, specific to B, related to the geometry of space-time, and the general dynamical/geometrical character of the fundamental physical entity (or entities), postulated by B.

Thus, the Boscovich blueprint may be so understood that it asserts that fundamental physical entities - point-particles with mass - are all of one type (symmetric with respect to particle exchange), rigid throughout all motions, and rotationally symmetric. The time evolution of any physical system is invariant with respect to translations in space and time, changes of orientation, and changes in fixed velocity with respect to some inertial reference frame. By contrast, the field/particle blueprint, as understood here, associated with classical electrodynamics - postulates the existence of two distinct kinds of fundamental entities, point-particles and fields of force; it asserts that force-fields are non-rigid (changes in the field travelling at some definite, finite velocity). This means that spherical-symmetry will be restricted to the case when a charged particle is motionless in a spatial region within which the field is otherwise zero. Again, whereas the Boscovich blueprint may be taken to imply Galilean invariance, the field/particle blueprint may be taken to imply Lorentz invariance.

A level 2 theory, T, may clash with physicalism and yet exemplify physicalism to some degree, in that it is disunified to some degree in one or more of the following eight ways of being disunified.

(1) T has a different CONTENT in the N different space-time regions, R1,...RN,

(2) T postulates that, for distinct ranges of physical variables, such as mass or relative velocity, in distinct regions, R1,...RN of the space of all possible phenomena, distinct dynamical laws obtain.

(3) T postulates, in an arbitrary fashion, N distinct, unique, spatially restricted objects, each with its own distinct, unique dynamic properties.

(4) T postulates N different kinds of physical entity,[17] differing with respect to some dynamic property, such as value of mass or charge, and interacting by means of different forces.
(5) As in (4) except the distinct kinds of physical entity interact by means of the same force.
(6) Consider a theory, T, that postulates N distinct entities (e.g. particles or fields), but these N entities can be regarded as arising because T exhibits some symmetry. If the symmetry group, G, is not a direct product of subgroups, we can declare that T is fully unified; if G is a direct product of subgroups, T lacks full unity; and if the N entities are such that they cannot be regarded as arising as a result of some symmetry of T, with some group structure G, then T is disunified.

The way in which relativistic classical electromagnetism unifies the electric and magnetic fields is an example of this kind of unity. Given the electric field, then the magnetic field must be adjoined to it if the theory is to exhibit the symmetry of Lorentz invariance. Again, the way in which chromodynamics brings unity to the eight gluons, and to quarks that differ with respect to colour charge, postulated by the theory, provides another example of this kind of unity. The diverse gluons and colour charged quarks of the theory are required to exist if the theory is to have its distinctive locally gauge invariant character, in this case the symmetry group being SU(3). The electroweak theory of Salam and Weinberg is an example of partial unity of this type, in that, in this case, the symmetry group, corresponding to the locally gauge invariant character of the theory, is SU(2) X U(1) - a group that is a direct product of subgroups. The theory only partially unifies the diverse quanta of the associated fields, the photon of electromagnetism and the vector bosons of the weak force.[18]
(7) If (apparent) disunity has emerged as a result of a series of cosmic spontaneous symmetry-breaking events, there being manifest unify before these occurred, then the relevant theory, T, is unified. If current (apparent) disunity has not emerged from unity in this way, as a result of spontaneous symmetry-breaking, then the relevant theory, T, is disunified.
(8) According to GR, the force of gravitation is merely an aspect of the curvature of space-time. As a result of a change in our ideas about the nature of space-time, so that its geometric properties become dynamic, a physical force disappears, or becomes unified with space-time. This suggests the following requirement for unity: space-time on the one hand, and physical particles and forces on the other, must be unified into a single self-interacting entity, U. If T postulates space-time and physical "particles and forces" as two fundamentally distinct

kinds of entities, then T is not unified in this respect.

We have here, then, eight DIFFERENT ways in which the totality of fundamental physical theory can exemplify physicalism to some degree N (with N = 1 for unity). The most severe kind of disunity is that specified by (1); (2) and (3) specify slightly less severe kinds of disunity, (4) and (5) less severe kinds of disunity still, and (8) specifies the least severe kind of disunity of all. (1) to (8) are to be understood as indicating eight different kinds of degrees of disunity, but not as DEFINING disunity.

Analogously, T may clash with a blueprint, B, and yet exemplify B to some degree, in that it postulates B-type entities, forces and symmetries, but at the same time violates, to some degree, and in one or more ways, the specific kind of unity postulated by B. The ways in which T violates B may differ in some respects from the eight ways in which T may violate physicalism. If B is the Boscovichean blueprint, only the first five of the eight unity/disunity distinctions just specified are relevant. In this case, B does not postulate anything like a force exhibiting local gauge invariance (6); it does not postulate spontaneously broken symmetries (7); and it does not unify space-time and matter (8). Consequently, even though T fails to be unified in ways (6), (7) and (8), this does not mean that T lacks B-type unity. If, on the other hand, the point-particles postulated by T have force-fields that lack rigidity and spherical symmetry, this would constitute a violation of B-type unity or simplicity, even though this does not, as such, violate physicalism.

Given two distinct blueprints, Bn and Bn+1, which postulate somewhat different kinds of entities, forces and symmetries (even though there is some overlap), we have two distinct notions of simplicity, Bn-simplicity and Bn+1-simplicity. A theory, T, may have a high degree of Bn-simplicity, and a low degree of Bn+1-simplicity.

Blueprints can themselves be assessed with respect to simplicity, with respect, that is, to how well they exemplify physicalism.

The simplicity of level 2 theories can, in short, be assessed in two distinct ways, in terms of what may be called P-simplicity and B-simplicity (degree of exemplifying physicalism and some blueprint, B, respectively).[19] The P-simplicity of a theory, T, assesses how successfully T realizes physicalism, and remains fixed as long as physicalism does not change its meaning. The B-simplicity of T assesses how well T realizes the best available overall blueprint for physics; B-simplicity evolves with evolving blueprints. Furthermore, that blueprints evolve with evolving knowledge is, according to AOE, essential to the rationality of science, a vital, necessary component of scientific progress (granted that we are ignorant of what version of physicalism is true). There is thus, according to AOE, no mystery about evolving notions of simplicity; that the notion of simplicity should evolve is essential to rationality, a vital component of progress. Simplicity criteria, associated with level 3 blueprints, do not merely change; they can improve. We learn more about the precise way in which Nature is simple or unified as science progresses.

This, in barest outline, is the aim-oriented empiricist solution to the problem of what simplicity IS.[20]

5 CONTENT AND FORM

Why does this proposed AOE solution to the problem of what simplicity is succeed where all orthodox empiricist attempts at solving the problem fail? The decisive point to appreciate is that, according to AOE, in assessing the relative simplicity of two theories, T1 and T2, what matters is the CONTENT of the two theories, not their FORM. It is what theories ASSERT about the world that must accord, as far as possible, with physicalism, with the thesis that a unified SOMETHING runs through all phenomena. Thus questions of formulation, axiomatic structure, etc., are essentially irrelevant when it comes to assessing the simplicity of theories in a methodologically significant sense. The fact that a theory may seem simple when formulated in one way, highly complicated or ad hoc when formulated in another - a fact that defeated attempts at solving the problem indicated in section 2 above - has, according to AOE, no bearing whatsoever on the simplicity or unity of the theory in an epistemologically and methodologically significant sense, which has to do exclusively with WHAT THE THEORY ASSERTS ABOUT THE WORLD. (which remains constant throughout mere terminological reformulations). What matters, in short, is the simplicity or unity, not of the THEORY ITSELF, but of what the theory ASSERTS TO BE THE CASE. A perfectly simple or comprehensible possible universe may be depicted by a theory that is formulated in a horribly complex fashion; and vice versa, a horribly complicated or incomprehensible universe may be depicted by a theory formulated in a beautifully simple way.

Consider a grossly ad hoc version of Newtonian Theory (NT), disunified in type (1) way of the last section, the most severe kind of disunity. This theory (NT1) asserts: "F = Gm1m2/d2 for times before 12 pm, 31st December 2005 and F = Gm1m2/d3 for times at or after 0.0 am, 1st January 2006". One could, however, introduce new terminology so that this manifest disunity disappears. By "1/d[n]" we mean: "1/dn" for times before 12 pm, 31st December 2005 and "1/dn+1" for times at or after 0.0 am, 1st January 2006". The force law for NT1 can now be written as: F = Gm1m2/d[2]. All aberrance and disunity has, it seems, disappeared.

But this is only terminological annihilation of disunity. The moment we ask what "F = Gm1m2/d[2]" ASSERTS, it is clear that the CONTENT of this sentence is highly disunified and aberrant.

In opposition to this, it may be argued, along lines that Goodman has made famous,[21] that aliens might do all their mathematics and physics in terms of notation and concepts like "1/d[n]". In terms of THEIR notions, it would be non-aberrant Newtonian theory which would be aberrant, in that, formulated in terms of the "1/d[n]" notation, a special mention would have to be made of the 31st December, 2005. Is there not symmetry here, between our concepts and notations, and the aliens'? If so, what basis can there be for declaring NT non-aberrant, and NT1 aberrant?

I have two replies to this objection.

First, it is important to appreciate that the objection presupposes that the aliens have the same notions of invariance, of things remaining the same through change, as we do. This is clear from the assumption that both we and the aliens regard F = Gm1m2/d[2] as terminologically invariant in time. But if we and the aliens agree on invariance in time as far as TERMINOLOGY is concerned, we ought also to agree on invariance in time as far as the CONTENT of the law is concerned. But we don't. The aliens are inconsistent. They have one notion of invariant in time as far as terminology is concerned, another as far as content is concerned. The time non-invariance of the content of "F = Gm1m2/d[2]" is clear from the fact that, presented with a running mechanical model of some solar system with planets moving in accordance with F = Gm1m2/d[2], both we and the aliens would be able to tell immediately whether a time before or after midnight on 31st December 2005 was being represented (inverse square and inverse cube laws of gravitation producing quite different motions[22]). This cannot be done if the model is operating to illustrate the content of "F = Gm1m2/d2". This establishes that whereas the content of "F = Gm1m2/d2" is time invariant, the content of "F = Gm1m2/d[2]" is not.

My second reply is much more heavy-handed and brusque. Physicalism is to be interpreted as being incompatible with any theory that is aberrant (non-invariant in space and time), and ALSO incompatible with any theory that is equivalent in content to an aberrant theory when formulated in our (non-alien) concepts, irrespective of whether or not the theory can be formulated in a terminologically non-aberrant way (employing alien terminology).

Analogous considerations apply in connection with the other six types of disunity indicated above.

6 SOLUTIONS TO REMAINING SIMPLICITY PROBLEMS

So far I have indicated how AOE solves the first two problems concerning what simplicity is: the terminological problem, and the problem of changing, or evolving, conceptions of simplicity. What about the remaining four problems indicated above? I take these in turn.

(iii) The multi-faceted problem. AOE is quite clear: the key notion behind the generic term "simplicity" is unity or explanatoriness. These two notions are connected as follows. The more UNIFIED a dynamical theory is, other things being equal, so the more EXPLANATORY it is. To explain, in this sense, is, ideally, to show that apparently diverse phenomena are really just different versions of the ONE kind of phenomenon, differing only with respect to initial conditions but otherwise evolving in accordance with the same force. Thus NT explains the diverse phenomena it predicts by revealing that these phenomena all evolve in accordance with Newtonian gravitation. As long as the totality of physical theory is disunified, explanation is inadequate; the explanatory task of physics is only at an end when all physical phenomena have been shown to be just ONE kind of phenomenon, all differences being differences of initial conditions of the ONE kind of entity or stuff.[23]

Other terms banded about - simplicity, symmetry, elegance, beauty, comprehensibility, etc. - all devolve, more or less straightforwardly, from the central notion of unity-throughout-diversity, or explanatoriness. Thus the requirement that a theory satisfies symmetry principles is related to unity in the ways indicated in (6) and (8) above, on pages 14-16.

It may be asked: Does simplicity (in the non-generic sense) play a role in distinguishing between physically comprehensible and incomprehensible universes? If it does, it takes second place to considerations of unity. This point is best discussed in connection with the fourth problem.

(iv) The problem of ambiguity. General relativity (GR) is, in a quite straightforward sense, a much more complicated theory than Newton's theory of gravitation (NT). NT determines the gravitation field by means of ONE equation, whereas GR requires a system of SIX equations. Furthermore, NT is a linear theory, in the sense that, as one adds more massive bodies to a system of bodies, the gravitational forces due to the new bodies merely add on to the forces already present. GR, on the other hand, is non-linear: the gravitational field interacts with itself. (The gravitational field itself contains energy, which induces curvature into space-time, and thus has gravitational effects.) Finally the equations of GR are vastly more difficult to solve than those of NT; GR is much more complex than NT in terms of the pragmatic notion of simplicity indicated above.

GR has, however, much greater unity than NT. According to NT, gravitation is a force that exists as something entirely distinct from, and in addition to, space and time; according to GR, gravitation is nothing more than the variable curvature of space-time. The field equations of GR specify how the presence of mass, or energy more generally, causes space-time to curve. According to GR, bodies "interacting gravitationally" do not, in a sense, interact at all; all bodies move along the nearest thing to straight lines in curved space-time, namely curved paths called geodesics, the four-dimensional analogue of great circles on the earth's surface. Geodesics are curves of exremal length in the sense that the length between any two points is unchanged to first order by small changes to the curve. Ordinarily one would think of the earth's motion round the sun as constituting a spiral in four dimensional space-time; according to GR, the mass of the sun causes space-time near the sun to be curved in such a way that the path executed by the earth is a geodesic in space-time.

GR unifies by eliminating gravitation as a force distinct from space-time; space-time has a variable curvature, as a result of the presence of matter or energy, and this variable curvature affects what paths constitute geodesics, and thus what paths bodies pursue; gravitation, as a force, vanishes. As a result, GR does not need an analogue to Newton's second law $F = ma$; all that is required is a generalization of Newton's first law: every body continues in its state of rest or uniform motion in a straight line, except in so far as a force is imposed upon it. ("Uniform motion in a straight line in Euclidean space" needs to be generalized to become "geodesic in Riemannian space-time".)

Despite its greater complexity, GR exemplifies physicalism better than NT because of its greater unity. And there is a further, crucial point. Given the basic unifying idea of GR, namely that gravitation is nothing more than a consequence of the variable curvature of space-time, the equations of GR are just about the simplest that are possible. The complexities of GR are not fortuitous; they are inevitable, granted the fundamental unifying idea of GR.

From this discussion of NT and GR we can draw the following general conclusion. Given two theories, T1 and T2, if T2 has greater unity than T1 then, other things being equal, T2 is the better theory from the standpoint of non-empirical considerations, even if T2 is much more complex than T1. This will be the case, especially, if the greater complexity of T2 is an inevitable consequence of its greater unity. Simplicity considerations may have a role to play, on the other hand, if there are two theories, T1 and T2, that are unified equally, in the same way, so that, at a certain level, T1 and T2 have a common blueprint, but T1 is much simpler than T2. In this case, T1 is a better theory than T2 on non-empirical grounds. A universe that exemplifies unity in a way that is highly complex in comparison with other possible universes (other possible dynamic structures) unified in the same sort of way, is, we may argue, not fully comprehensible. To this extent, comprehensibility requires simplicity.[24] (We have here a ninth way of drawing the distinction between unity and disunity, to be added to the eight indicated above.)

The extent to which simplicity considerations, of this limited type, ultimately play a role in what it means to say that the universe is comprehensible depends, to some extent, on the character of the true theory of everything, T. Given T, there are, we may assume, any number of rival theories, T1 ... Tn, that exemplify physicalism just as well as T does, as far as the eight requirements for unity indicated above are concerned. It is conceivable that a level 3 blueprint, B, can be specified which is such that T, together with a proper subset of T1 ... Tn, are all equally well B-unified, as far as the eight requirements for unity are concerned, but ONE of these B-unified theories is much simpler than the others. In this case we could declare that, for unity, we require that the simplest of these theories is true.

(v) The problem of doing justice to the intuition of physicists.
I shall restrict myself to considering just five points (five items of data, as it were, that any theory of simplicity ought to be able to account for). First, physicists are generally at a loss to say what simplicity is, or how it is to be justified. Second, despite this, much of the time most theoretical physicists are in broad agreement in their judgements concerning the non-empirical simplicity requirements that theories must satisfy to be accepted, at least to the extent of agreeing about how to distinguish non-ad hoc from ad hoc theories.[25] But third, in addition to this, non-empirical simplicity criteria intuitively accepted by physicists tend to change over time. Fourth, during theoretical revolutions there are often spectacular, irreconcilable disagreements.[26] Rationality tends to break down during revolutions, as graphically described by Kuhn.[27] But fifth, despite all this, intuitive ideas concerning simplicity, at least since Newton, have enabled physics to meet with incredible (apparent) success.

According to the account of simplicity being advocated here, the more nearly the totality of fundamental dynamical theory exemplifies physicalism, so the greater is its degree of simplicity. In practice physics accepts physicalism, even though this may be denied by physicists (because it clashes with the official standard empiricist doctrine). This view accounts for the above five points as follows.

The failure of physicists to say what simplicity is, or how it should be justified, is due to the fact that most physicists accept that simplicity considerations play an important role in science but reject AOE; within such a framework no adequate account of the role of simplicity in physics can be given, as we have seen. The general, more or less implicit acceptance of physicalism in practice means that there is, in practice, at any given time, broad agreement concerning judgements of simplicity. (Physicists may merely require that any acceptable theory must be such that it can be given some more or less specific kind of formulation: but this in practice is equivalent to demanding that any theory accord with some blueprint corresponding to the concepts, the language of the formulation, as we shall see below.)

According to AOE, even if at level 4 there is no change of ideas, at level 3 it is entirely to be expected that there will be changes over time. (It would be astonishing if, at level 3, the correct guess was made at the outset.) The historical record reveals just such an evolution of blueprint ideas, from the corpuscular hypothesis, via the Boscovichean blueprint, the classical field blueprint, the empty space-time blueprint (with variable geometry and topology), the quantum field blueprint, Lagrangianism, to the superstring blueprint. Thus, over time, judgements concerning simplicity both do, and ought to, evolve with evolving level 3 blueprint ideas. During theoretical revolutions, it is above all level 3 blueprint ideas that change. During such revolutions, some physicists will hold on to the old, familiar blueprint, while others will embrace the new one. This means that physicists will assess the competing theories in terms of somewhat different conceptions of simplicity, related to the different, competing blueprints. General agreement about simplicity considerations will, in these circumstances, break down. Arguments for and against the competing theories will be circular, and rationality will tend to break down in just the way described so graphically by Kuhn. Finally, the success of physics is due, in large part (a) to the acceptance in practice of physicalism (or some fruitful special case such as the corpuscular hypothesis or Boscovicheanism), and (b) to the fact that physicalism is either true or, if false, "nearly true" in the sense that local phenomena occur as if physicalism is true to a high degree of approximation.

(vi) It deserves to be noted that AOE does not merely account for basic facts about physicists' intuitions; it clarifies and improves on those intuitions. Once AOE is generally accepted by the physics community, the breakdown of rationality during theoretical revolutions, noted by Kuhn, will no longer occur. If the revolution is a change from theory T1 and blueprint B1 to theory and blueprint T2 and B2, an agreed framework will exist for the non-empirical assessment not only of T1 and T2, but of B1 and B2 as well. Kuhn argues that the breakdown of rationality during revolutions is due to the fact that, ultimately, only empirical considerations are rational in science. During a revolution, empirical considerations are inconclusive; the new theory, T2, will not have had time to prove its empirical mettle (etc.). Thus rational assessment of rival theories must be highly inconclusive. Insofar as physicists appeal to rival paradigms (as Kuhn calls them), B1 and B2, the arguments are circular, and thus irrational (persuading only those who already believe). Accept AOE, and this situation changes. Rational considerations do exist for the (tentative) assessment of the relative merits of B1 and B2; we are justified in assessing how adequately they exemplify physicalism. This means, in turn, that we can judge rationally whether we are justified in assessing T2 (or T1) in terms of B2. Such judgements, though rational, will be fallible even if physicalism is true: acceptance of AOE thus makes clear that dogmatism, at the level of paradigms, or level 3 blueprints, is wholly inappropriate. This in itself promotes rationality in physics.

7 TERMINOLOGICAL SIMPLICITY

It may be objected that the above theory of simplicity, stressing CONTENT to the exclusion of FORMULATION, establishes too much. Simplicity of formulation DOES matter in physics! What is so puzzling about simplicity in science is that simplicity of formulation does matter, even though it also clearly cannot matter at a fundamental level. In deciding what theories to accept and what theories to reject, scientists are constantly, and quite properly, guided by the simplicity or complexity of the FORMULATION of theories.

But this too can easily be accounted for by the present AOE-theory of simplicity. The acceptability or unacceptability of theories T1,...Tn, from the standpoint of simplicity or unity, depends upon how well or ill the physical content of these theories satisfies the symmetries of the best available level 3 blueprint for physics, which in turn depends on the physical content of the blueprint (and not on its formulation). So far formulation or language is entirely irrelevant. However, the decision to employ a set of basic concepts, C, to formulate physical theories in effect amounts to adopting a blueprint BC. The better the physical content of a theory, T, satisfies the symmetries of BC so the simpler the formulation of T will tend to be, when formulated in the corresponding concepts C. Thus the simplicity or complexity of the formulation of a theory, T, is relevant to the acceptability of T if the concepts, C, used to formulate T correspond to the best available blueprint for physics; otherwise the simplicity or complexity of the formulation of T is irrelevant to the acceptability of T. Here, in a nutshell, is the solution to the problem - utterly baffling when viewed from an orthodox empiricist position - of how the simplicity or complexity of FORMULATION of a theory can be both HIGHLY RELEVANT to the acceptability of the theory, and UTTERLY IRRELEVANT.

What does it mean to say that a set of concepts, C, or a language, L, corresponds to a blueprint B? The answer is straightforward. L corresponds to B when the physical terms of L (the physical concepts of C) have meanings which presuppose the truth of B - as when Newtonian concepts of space, time, mass and force presuppose the truth of the corresponding facets of the Newtonian blueprint. Furthermore, L corresponds to B when the symmetries of B are reflected in L.[28] Granted that the most acceptable blueprint for physics postulates that space-time is Minkowskian in character, then the fact that a theory T takes on a simple form when formulated in a Lorentz-invariant language, which incorporates the symmetries of Minkowskian space-time, is highly significant from the standpoint of the acceptability of T.[29] The fact that T has a highly complex form when formulated in some other language, not related to Minkowskian space-time, whereas another theory T* has a highly simple form in this other language, is neither here nor there from the standpoint of acceptability (granted that space-time IS Minkowskian, or at least is asserted to be so by the most acceptable blueprint).

One way in which simplicity of form registers itself in a methodologically significant way in physics is through RELATIVE simplicity. Given an empirically highly successful theory, T, about some range of phenomena, it is methodologically significant that a new theory, T*, about some different range of phenomena, has a simple form relative to T - i.e. has a simple form when formulated in the language L within which T has a simple form. The fact that both T and T* have simple forms in L indicates that they satisfy well the symmetries of the best blueprint B, corresponding to L (or implicit in the choice of L as the basic language of theoretical physics). In line with this, theoretical physicists strive to formulate new theories in a way which is as close as possible to the form of pre-existing, empirically successful theories, modifications being introduced only to the extent that these are necessary to accommodate the different circumstances with which the new theory deals. Examples are the way in which classical electrodynamics arose as a series of modifications to NT, and the way in which quantum electroweak theory and quantum chromodynamics arose as a result of keeping as close as possible to the form of the pre-existing, empirically highly successful theory of quantum electrodynamics, only those modifications being introduced which were necessary in order to accommodate those features of the weak and strong forces that differ from the electromagnetic force.

Furthermore (in line with this same point) theoretical physicists were highly encouraged, two decades or so ago, when they realized that the three fundamental theories of physics have one symmetry feature in common with one another - local gauge invariance. (Even GR has a local gauge invariant aspect.) This common symmetry feature was taken to be an indication of the underlying unity of Nature, and a sign that theoretical physics was on the right road. All this makes perfect sense according to the AOE theory of simplicity or unity developed here.

It might seem, at first sight, that a theory of simplicity which concentrates on unity at the level of fundamental theory can have little to say about simplicity at the humble level of empirical laws, remote from fundamental theory. But the considerations just mentioned show that this is not the case. An empirical law, however complex, can always be turned into a law that is as simple as we please by an appropriate change of concepts. (The demand for simplicity appears to be vacuous.) What prevents us from doing this in scientific practice is the demand for unity: we require that, as far as possible, diverse laws are formulated in terms of the SAME basic concepts. The introduction of new concepts at the empirical level needs to be kept to a minimum, and such concepts need to be related to, or explicated in terms of, concepts associated with the best available blueprint (as when the notion of temperature of a gas is related to average kinetic energy of the constituent molecules). It is the demand for theoretical unity, in other words, which makes the demand that empirical laws should have a simple form a non-vacuous demand (and one which often cannot be fulfilled).[30]

8 IS THE THEORY CIRCULAR?

The correct theory of simplicity ought itself to be simple. It may be felt, however, that the above is altogether too simple in that it is circular. The unity of THEORIES is explicated in terms of the unity of PHYSICALISM. What has been achieved?

If the task was to give some sort of philosophical analysis of the concept of unity, this objection might be well-founded, but this is not what is required in order to solve the problem of what simplicity is. The task, rather, is to solve the problems, (i) to (vi), that arise in connection with attributing degrees of simplicity to theories. In order to solve these problems, it is essential to associate simplicity with content and not form. But this means that we require, at some level, a substantial thesis about the nature of the universe, the content of which is taken to be paradigmatic of simplicity (or unity). We cannot take some level 2 theory as paradigmatic of unity because, in our present state of ignorance, any theory we pick out is almost bound to be false (the associated notion of unity being inapplicable to the actual universe). Nor, for the same reason, can we take a level 3 blueprint to exemplify unity. The conjecture is that, as long as the level 4 thesis of physicalism is sufficiently IMPRECISE, it will turn out to be true; it thus constitutes the best paradigm of unity that we are in a position to formulate in our present state of partial knowledge and ignorance.[31] As long as the metaphysical thesis of physicalism is a MEANINGFUL assertion, explicating the unity of theories in terms of how well or ill they exemplify physicalism does not introduce an illegitimate circularity into the proposed solution to the problems of attributing unity to theories. There is, in other words, no circularity in "the more nearly a theory exemplifies physicalism, the more unified it is"; all that is required is that one can make sense of the idea that one theory may exemplify physicalism more nearly than another theory (which I have demonstrated above), and that physicalism is a meaningful thesis.

But is physicalism meaningful, given its lack of precision? Some philosophers, physicists and mathematicians may be inclined to believe that only those assertions whose meanings are absolutely precise are meaningful at all. This rests on a false theory of meaning. Meaningful assertions can be more or less precise, more or less vague. The mere vagueness of physicalism does not provide grounds for holding that physicalism is meaningless.

Furthermore, in support of the meaningfulness of physicalism it can be argued that the doctrine is bounded by undeniably meaningful assertions from below, and from above. Many undeniably meaningful more or less precise versions of physicalism can be exhibited in the form, either, of precise, level 2, testable, unified theories-of-everything, or of less precise level 3 blueprints. Again, physicalism is a special case of the more general level 5 thesis of comprehensibility, exemplified not only by physicalism, but by such conjectures as God, or a tribe of gods, exists everywhere determining the way events unfold - conjectures which may be false but are hardly meaningless.

It might be thought that physicalism is meaningless because it excludes nothing, it can never be false. But this is not true: there are a multitude of ways in which physicalism can be false. All that is required is that nothing exists which is the same everywhere and determines the way events unfold.[32]

9 IS THIS ACCOUNT OF SIMPLICITY RESTRICTED TO PHYSICS?

Can the above account of simplicity, applicable to fundamental theories of physics, be extended so as to be applicable to the whole of natural science? The answer is: Yes. Fundamental physical theories can be partially ordered with respect to simplicity by means of the extent to which their content exemplifies the best available (level 3) blueprint, or the (level 4) thesis of physicalism. Less fundamental parts of physics, and other parts of natural science, can be partially ordered with respect to simplicity by means of the extent to which their content accords with the content of accepted fundamental physical theories. Natural science is not made up of intellectually isolated disciplines. The less explanatory fundamental parts - phenomenological physics, astrophysics, astronomy, geology, chemistry, biology - are constrained by more fundamental parts, and ultimately accepted fundamental theories of physics. It is this which makes it possible to apply the above account of simplicity to the whole of natural science.

This concludes my account of how AOE solves the problem of what simplicity is.

10 HOW IS PREFERENCE FOR SIMPLE THEORIES TO BE JUSTIFIED?

It is not always appreciated that the problem of justifying preference for simple theories in science is the nub of the problem of induction. For if this problem can be solved, the task of justifying acceptance of theories that satisfy both empirical and simplicity considerations sufficiently well (the problem of induction) is automatically fulfilled.

Granted the above AOE theory of what simplicity is, justifying persistent preference for simple theories amounts to justifying acceptance of physicalism as a part of scientific knowledge. But how can this be done? Is not AOE merely a baroque version of that much discredited approach to the problem of induction which seeks to solve the problem by appealing to, and justifying, some principle of the uniformity of Nature? Physicalism is a particularly strong principle of uniformity, and thus particularly difficult to justify which, on the face of it, just makes things worse.

In what follows I show how AOE overcomes three standard objections to the approach of solving the problem of induction by appealing to uniformity principles, and then indicate briefly how AOE actually solves the problem.[33]

Physicalism is not the only uniformity principle that AOE appeals to: theses at levels 3 and 4 to 9 are all uniformity principles, and even the thesis of partial knowability, at level 10, may be regarded as a highly restricted, qualified uniformity principle. The three standard objections to this approach are the following.

(1) Any attempt to solve the problem in this way must rest on a hopelessly circular argument. The success of science is justified by an appeal to some principle of the uniformity of Nature; this principle is then in turn justified by an appeal to the success of science. As Bas van Fraassen has put it "From Gravesande's axiom of the uniformity of nature in 1717 to Russell's postulates of knowledge in 1948, this has been a mug's game".[34]

(2) Even if, by some miracle, we knew that Nature is uniform in the sense that the basic laws are invariant in space and time, this still would not suffice to solve the problem of induction. Given any empirically successful theory, T, invariant in space and time, there will always be infinitely many rival theories which will fit all the available data just as well as T does, and which are also invariant in space and time.

(3) We cannot even argue that the principle of uniformity, indicated in (2), must be accepted because only if the principle is true is it possible for us to acquire knowledge at all. One can imagine all sorts of possible universes in which knowledge can be acquired even though the uniformity principle, as indicated above, is false.

These objections may well be decisive against some traditional attempts to solve the problem of induction by appealing to a principle of the uniformity of Nature, but they are harmless when directed against AOE.

What differentiates earlier "uniformity" views from AOE is that whereas the earlier views appeal to just ONE (possibly composite[35]) principle of uniformity, strong AOE appeals to eight distinct uniformity principles upheld at eight distinct levels, these principles becoming progressively more and more contentless as we ascend from level 3 to level 10. This difference is decisive as far as the above three objections are concerned.

REPLY TO (1): It is obviously fallacious to justify the uniformity of Nature by an appeal to the success of science, and then justify the success of science by an appeal to the

uniformity of Nature. Any view which appeals to just ONE (possibly composite) uniformity principle becomes fallacious in this way the moment it appeals to the success of science. The only hope of a valid solution to the problem along these lines is to justify accepting the specified uniformity principle on the grounds that there is no alternative: if the principle is FALSE, all hope of acquiring knowledge disappears, and thus we risk nothing in assuming the principle to be true. Just this kind of justification is given by AOE for principles accepted at levels 10 and 9 - a kind of justification which makes no appeal to the success of science, and thus entirely avoids the above fallacy.
In addition, however, according to AOE, we need to choose between rival, much more specific, contentful uniformity principles in such a way that we choose those that seem to be the most fruitful from the standpoint of promoting the growth of empirical knowledge. Choice of principles, at levels 3 to 8, IS influenced by the (apparent) success of science, or the (apparent) success of research programmes within science. But this does NOT mean that AOE commits the above fallacy of circularity. As I have already remarked, principles at levels 9 and 10 are justified without an appeal to the success of science. One then has to consider rival hierarchies to those of current science: rival level 2 theory, T*, plus rival theses at levels 3 to 8. Let the hierarchy of current AOE science be H and some rival hierarchy be H*. Three considerations, at least, arise in connection with assessing the relative merits of H and H*. (a) How well does the hierarchy accord with theses at levels 9 and 10? (b) How successfully does the level 2 theory predict phenomena at level 1? (c) How well does each thesis in the hierarchy exemplify the one above? H is preferable to any rival H* if it as least as good as H* in all three respects, and better in at least one respect. There is not a hint, here, of a circular argument.[36]
Reply to (2): As a result of specifying eight uniformity principles, graded with respect to content, AOE is able to uphold, at level 3 or 4, uniformity principles much stronger than the principle that laws should be uniform in space and time, sufficiently strong indeed to pick out, at any given stage in the development of physics, that small group of fundamental dynamical theories that do the best justice (a) to the evidence and (b) to the best available level 3 or level 4 principle.
Reply to (3): Traditional "uniformity" views that appeal to just one uniformity principle have the impossible task of formulating a principle which is simultaneously (i) sufficiently strong to exclude empirically successful ad hoc theories and (ii) sufficiently weak to be open to being justified along the lines that it is impossible to acquire knowledge if the principle is

false. AOE, as a result of specifying eight principles, graded with respect to content, is not required to perform this impossible task. At levels 9 and 10 uniformity principles are accepted that are sufficiently weak to be justified along the lines that it is impossible to acquire knowledge if they are false; at levels 3 and 4 principles are adopted that are sufficiently strong to exclude empirically successful aberrant theories. These latter principles are not such that they must be true if any advance of knowledge is to be possible; circumstances are conceivable in which these strong principles ought to be revised in the interests of further acquisition of knowledge. Indeed, at level 3, such revisions have occurred a number of times during the development of modern physics.

In outline, then, the proposed solution to the problem of induction amounts to this. All our knowledge is ultimately conjectural in character; the most that the solution the problem of induction can achieve is to show that we are justified in adopting certain conjectures as a basis for action, rival conjectures deservedly being rejected.

We are justified in accepting the cosmological assumptions that the universe is partially knowable and epistemologically non-maliciousness, at levels 10 and 9, because we have nothing to lose; it cannot harm the pursuit of knowledge to accept these assumptions in any circumstances whatsoever. The same cannot be said for the level 8 assumption of meta-knowability: if we accept this assumption and it is false, we will be led fruitlessly to search for improved methods for the improvement of knowledge. On the other hand, granted that it is possible for us to acquire knowledge (as level 10 and 9 theses assert), it is not unreasonable to suppose that existing methods for the improvement of knowledge can be improved. Unless we try to discover improved methods for the improvement of knowledge, we are unlikely to discover such methods, even if meta-knowability (relative to our existing knowledge) is true. And if new methods rapidly generate new knowledge that satisfies existing criteria for knowledge, and survive our most ferociously critical attempts at refutation, then the thesis of meta-knowability deserves to be taken very seriously indeed. The immense apparent success of science fulfils these conditions, and indicates that meta-knowability deserves to be adopted as a part of our conjectural knowledge.

Granted level 1 evidence and the level 3 thesis of Lagrangianism, current fundamental physical theories, the standard model and general relativity, deserve to be accepted. But why should Lagrangianism be accepted? Granted the evidence and the level 4 thesis of physicalism, there is no other available cosmological conjecture, at an equivalent level of generality, that has appeared to be as fruitful for the generation of (level 2) theoretical knowledge as Lagrangianism. But why should physicalism be accepted? Granted the evidence and the level 5 thesis of comprehensibility, there is no other conjecture, at an equivalent level of generality, which has appeared to be so fruitful for the generation of (level 2) theoretical knowledge as physicalism. Why should the comprehensibility thesis be accepted? Granted acceptance of the level 6 thesis of near comprehensibility, it is all but tautological that the level 5 thesis of perfect comprehensibility should be accepted. But why should near comprehensibility be accepted? Because, granted the level 7 thesis of rough comprehensibility, no thesis other than near comprehensibility, at a comparable level of generality, has appeared to be as fruitful for the generation of level 2 knowledge. And why should rough comprehensibility be accepted? Because, granted the level 8 thesis of meta-knowability, no other thesis, at a comparable level of generality, has appeared to be as fruitful for the generation of level 2 knowledge.

This, in outline, is how AOE solves the problem of induction, this solution solving the problem of justifying acceptance of physicalism, and thus justifying persistence preference for simple theories in science, as explicated above. The two basic problems of simplicity are solved.

NOTES

1. Earlier versions of this paper were given at the London School of Economics, at the University of Oxford, at the 7th UK Conference on the Conceptual Foundations of Physics at Nottingham University, at Warwick University, and at the Center for Philosophy of Science, Pittsburgh University.

2. Tradition has forced me to use the word "simplicity" in two different senses. On the one hand, in discussing "the problems of simplicity" (as it is traditionally called), I use the word as the generic term, to stand for all the terms that may be used in the present context: "unity", "explanatoriness", etc. On the other hand "simplicity" may be used to refer to just one (hypothetical) aspect of theories in addition to the other aspects. In this second sense, "simplicity" really does mean simplicity. I hope this ambiguity of usage is not too confusing.

3. R. Feynman, R. Leighton and M. Sands, The Feynman Lectures on Physics (Reading, Mass.: Addison-Wesley, 1965) vol. II, pp. 25-10 - 25-11.

4. H. Weyl, Philosophy of Mathematics and Natural Science (New York: Athenium, 1963) p. 155.

5. A. Einstein, "Autobiographical Notes" in P.A. Schilpp (ed) Albert Einstein: Philosopher Scientist (La Salle: Open Court,

1982) vol 1, pp. 21-25.
6. H. Jeffreys and D. Wrinch, "On Certain Fundamental Principles of Scientific Enquiry", Philosophical Magazine 42, 1921: 269-298.
7. K. Popper, The Logic of Scientific Discovery (London: Hutchinson, 1959) ch. VII.
8. N. Goodman, Problems and Projects, (New York: Bobbs-Merrill, 1972); M. Friedman, "Explanation and Scientific Understanding", Journal of Philosophy 71 (1974): 5-19; P. Kitcher, "Explanatory Unification", Philosophy of Science 48 (1981): 507-531; J. Watkins, Science and Scepticism, (Princeton: Princeton University Press, 1984) pp. 206-213.
9. For criticisms of Friedman's proposal, see: P. Kitcher, Explanation, Conjunction and Unification, Journal of Philosophy 73 (1976): 207-212; W. Salmon, Four Decades of Scientific Explanation (Minneapolis: University of Minnesota Press, 1989) pp. 94-101. For criticisms of Watkins' proposal see G. Oddie, "The Unity of Theories", in F. D'Agostino and I. Jarvie (eds) Freedom and Rationality: Essays in Honour of John Watkins (Dordrecht: Kluwer, 1989) pp. 343-368. For Watkins' reply see his: "Scientific Rationality and the Problem of Induction: Responses to Criticisms, British Journal for the Philosophy of Science 42 (1991): 343-368. For criticisms of Friedman, Kitcher and Watkins see: N. Maxwell, The Comprehensibility of the Universe, (New York: Oxford University Press, 1998) pp. 65-68.
10. For earlier expositions of AOE see: N. Maxwell, "A Critique of Popper's Views on Scientific Method", Philosophy of Science 39 (1972): 131-52; "The Rationality of Scientific Discovery" Philosophy of Science 41 (1974): 123-53 & 247-95; "Articulating the aims of science" Nature 265 (1977): 2; "Induction, Simplicity and Scientific Progress", Scientia 114 (1979): 629-53; From Knowledge to Wisdom (Oxford: Blackwell, 1984) ch. 9; "Induction and Scientific Realism", British Journal for the Philosophy of Science 44 (1993): 61-79, 81-101 & 275-305. For a detailed, recent exposition see N. Maxwell, The Comprehensibility of the Universe (Oxford: Oxford University Press, 1998), especially chs. 1 and 3. For a brief outline see: N. Maxwell, "Has Science Established that the Universe is Comprehensible?, Cogito 13, 1999, pp. 139-145. For an even briefer outline, see N. Maxwell, "A new conception of science", Physics World 13, No. 8, 2000, pp. 17-18. For a recent favourable assessment of AOE see: J. J. C. Smart, "Review", The British Journal for the Philosophy of Science 51, 2000, pp. 907-911.
11. For further discussion of the theses of comprehensibility and physical comprehensibility here indicated see N. Maxwell, The Comprehensibility of the Universe (Oxford: Oxford University Press, 1998), especially chs. 1 and 3-6.

12. The notion of "discoverable" is problematic. As I am using the term, no ad hoc thesis about the universe is discoverable if the purely ad hoc phenomena, postulated by the thesis, lie beyond our experience.

13. The theses at levels 3 to 10 are to be understood in such a way that they are relative to our existing knowledge at levels 1 and 2.

14. If the true theory-of-everything is discovered, then Pr implies Pr+1 for 2 ó r ó 9 (and, with the usual qualifications, P2 implies P1). In the absence of such a discovery, P2 may not imply P3 (as at present), and P3 may not imply P4.

15. For accounts of Lagrangian formulations of classical and quantum mechanical theories see: R. Feynman, R. Leighton and M. Sands, The Feynman Lectures, vol. II, ch. 19; F. Mandl and G. Shaw, Quantum Field Theory (New York: John Wiley, 1984) ch. 2; H. Goldstein, Classical Mechanics (Reading, Mass.: Addison-Wesley, 1980).

16. P9 is a kind of "principle of the uniformity of nature". P9 is, however, intended to be very much weaker than uniformity principles as these are usually formulated and understood. It does not assert that all phenomena are governed by the same laws everywhere, since the possibility of (some) ad hoc phenomena is conceded. Instead, P9 asserts that if ad hoc phenomena occur anywhere they occur in our immediate environment. P9 does not even assert that approximately lawful phenomena occur everywhere, but merely that whatever it is that makes our immediate environment partially knowable extends throughout the universe. We might live in a partially knowable world even though no laws strictly obtain, as the notion of law is understood in natural science.

17. Counting entities is rendered a little less ambiguous if a system of M particles is counted as (a somewhat peculiar) field. This means that M particles all of the same kind (i.e. with the same dynamic properties) is counted as one entity. In the text I continue to adopt the convention that M particles all the same dynamically represents one kind of entity, rather than one entity.

18. For accounts of the gauge group structure of quantum field theories see: K. Moriyasu, An Elementary Primer For Gauge Theory, 1983, World Scientific; I.J.R. Aitchison and A.J.G. Hey, Gauge Theories in Particle Physics, 1982, Adam Hilger, Part III; D. Griffiths, Introduction to Elementary Particles, 1987, John Wiley, ch. 11. For introductory accounts of group theory as it arises in theoretical physics see: C.J. Isham, Lectures on Groups and Vector Spaces for Physicists, 1989, World Scientific; or H.F. Jones, Groups, Representations and Physics, 1990, Adam Hilger.

See also N. Maxwell, The Comprehensibility of the Universe, Oxford University Press, 1998, Mathematical and Physical Appendix, Sections 3 - 5.

19. "Theory", throughout this discussion, means the conjunction of fundamental dynamical theories required to cover, in principle, all known phenomena, or the conjunction of laws of some domain of phenomena if no theory of the domain exists.

20. For a more detailed discussion see my The Comprehensibility of the Universe, especially ch. 4.

21. See N. Goodman, Fact, Fiction and Forecast, Athlone Press, 1954.

22. To make the point more obvious and dramatic, one could imagine that the aberrant version of NT asserts that, from the first moment of the year 2006 onwards, Newtonian gravitation becomes a repulsive force!

23. Strictly speaking, two non-empirical requirements are involved in the explanatory character of a theory. The explanatory character of a theory becomes all the greater the more (i) unified it is, and (ii) the greater its empirical content. This second requirement is related to the goal of theoretical physics of discovering unity throughout all the diverse physical phenomena that there are; the goal of theoretical physics, we might say, is to discover dynamic unity running through all possible diversity.

24. It is simplicity of content that is important, not simplicity of form.

25. If this were not the case, there would be no generally accepted theories in physics. Given any empirically successful non-ad hoc theory, T, there are infinitely many ad hoc rivals that are just as empirically successful. (In order to construct such ad hoc rivals, one need only modify T arbitrarily for some as yet untested region in the space of possible phenomena to which T applies.) Without general agreement that these rivals fail to satisfy non-empirical simplicity considerations, there would be no basis for excluding them from consideration. (Ad hoc theories may be accepted because it is not noticed how ad hoc they are: I have, for many years, argued that orthodox QT is unacceptably ad hoc in a widely unnoticed way, in that it is an ad hoc addition of quantum and classical postulates: see N. Maxwell, Am. J. Phys. 40 (1972): 1431-1435; Found. Phys. 6 (1076): 275-292 & 661-676 (1976); Brit. J. Phil. Sci. 39 (1988): 1-50; Phys. Lett. A 187 (1994): 351-355; The Comprehensibility of the Universe, ch. 7.

26. See, for example, Kuhn's discussion of such disagreements in his The Structure of Scientific Revolutions (Chicago: Chicago University Press, 1962) especially chs. VII-XII.

27. See especially ch.IX of Kuhn's The Structure of Scientific Revolutions.
28. When physical symmetries are reflected in the language used to describe the phenomena, symmetry transformations are of two kinds: 'active', involving a real physical change (such as a change of position or orientation in space) and 'passive', involving a change of description (a change of the position or orientation of the coordinate system in terms of which the phenomena are described).
29. For a lucid discussion of the simplicity of classical electromagnetism when formulated in such a Minkowski-appropriate language, see Feynman et al., The Feynman Lectures on Physics (Reading, Mass.: Addison-Wesley, Reading, Massachusetts, 1965) vol. II, pp. 25-8 to 25-11.
30. For earlier expositions of this account of simplicity see N. Maxwell, "The Rationality of Scientific Discovery, Part 2", Philosophy of Science 41 (1974): 247-95; "Induction, Simplicity and Scientific Progress", Scientia 114 (1979): 629-653. (For a fuller account, see my The Comprehensibility of the Universe, ch. 4.)
31. If physicalism is false, the required notion of simplicity, or unity, will have to be associated with the content of the level 5 thesis of comprehensibility, with some higher level thesis, or some alternative to physicalism or comprehensibility at level 4 or 5.
32. For a list of 16 rival theses to physicalism see my The Comprehensibility of the Universe, pp. 169-171.
33. For earlier expositions of this approach to the problem of induction see works referred to in note 10, especially my The Comprehensibility of the Universe (Oxford: Oxford University Press, 1998), ch. 5.
34. B. van Fraassen, "Empiricism in the Philosophy of Science", in P.M. Churchland and C.A. Hooker, (eds.) Images of Science (Chicago: University of Chicago Press, 1985) pp. 259-260.
35. Russell argues that five postulates are "required to validate scientific method": see B. Russell, Human Knowledge, (London: Allen and Unwin, 1948) p. 506. These postulates are not, however, ordered with respect to content and implication in the way specified by AOE: they are all on the same level and may, therefore, be treated as five components of one composite postulate.
[36] For further details see my The Comprehensibility of the Universe, ch. 5.