Hekmat va Falsafeh
(Wisdom and Philosophy)
Vol.4, No.2, August 2008, pp.81-109

حکمت و فلسفه
سال چهارم، شماره دوم، تابستان ۱۳۸۷

How Best to Make Sense of Science?

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Abstract

The issue of developing a rational framework for not only assessing scientific theories but also providing effective guidelines for satisfactory progress of science lies at the heart of modern methodological debates in the field of philosophy of science. During the past few decades, realists and anti-realists of every hue have tried to produce viable theories for science.

Any viable theory of science ought to be able to provide, among other things, satisfactory answers for the three following questions, namely, "What must the world be like for scientific knowledge not only to be possible but also to have the greatest chance of progress?"; "What aim and structure must science have to be successful, i.e., to give us knowledge of the observable as well as unobservable aspects of the physical universe?"; and "How must the methodology be like to maximize the success-rate of science?"

In what follows, making use of the ideas of a number of realists writers including Karl Popper, Roy Bhaskar and Nicholas Maxwell, I shall try to tackle the above questions. The upshot of the arguments of the paper is that a new type of realist approach, mostly based on the views of mature Popper (Popper post 1960s) but also enriched by the insights offered by some other realist writers provides not only a powerful framework for making rational sense of science but also an effective

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research tradition for the advancement of science.

Keywords: *Scientific Realism, Modern Anti-realism, Standard Empiricism, Aim-oriented Empiricism, Metaphysics.*

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Introduction

Modest scientific realists emphasise that any viable theory of science should be able to specify I) a (number of) basic, essential aim(s) for scientific enterprise; II) a set of methodological rules which are conducive, in a reasonably effective way, to the defined aim(s) and are governing choice of the best theory from among a number of rivals, and III) a demonstration to show that the proposed aim(s) and methodological rules are better than the alternative candidates.

Modern anti-realists are of the view that science should aim at empirical adequacy. They are adamant that scientific knowledge consists in the empirically adequate knowledge. In their view, scientific theories are either abstract equations, implicit definitions, or other highly sophisticated intellectual constructs. These products of human imagination need not be regarded as mere fictions or instruments (as was the case with the previous generations of anti-realists). Nevertheless, these constructs do not provide us with knowledge of the underlying, unobservable reality. Their main function is to provide scientists with a neat way of organizing and systematizing the empirical data and to facilitate the knowledge at the level of phenomena.

Modest scientific realists would argue that the proposed aim and methods of the celebrated modern anti-realist theories of science leave much to be desired. Modern anti-realists are not able to produce viable criteria for objective theory choice. The phenomenon of progress of science also poses a great difficulty for modern anti-realist theories. Furthermore, the all-important problem of induction remains unsolved, even untouched, within these anti-realist frameworks. These shortcomings on the part of anti-realists' programmes would render them unable to provide viable images of science and would push them towards the slippery slope of treating science as a mere intellectual game, with little relevance to the real scientific enterprise.

The fact that modest scientific realists or minimal realists have been able to level powerful criticism at the views of modern anti-realists does not mean that their own position is free from weaknesses and defects. Thus for example, the notion of verisimilitude, which was produced by a minimal realist like Karl Popper, despite all its intuitive appeal, is fraught with logical difficulties. It has also been suggested that the willingness of some realist writers to resort to extra-empirical values while limiting themselves to the confines of standard empiricism, renders their position inconsistent. In fact, it can be shown that within the confines of standard empiricism none of the major problems of rationality, e.g., problem of theory choice, can be solved satisfactorily.

What makes the case even more embarrassing for realists, who intend to make rational sense of science, is that it seems that working scientists, in deciding the fate of rival theories, as a matter of routine, resort to extra-empirical values, taking them as epistemically significant. Such a wide-spread practice among scientists, i.e., scientists' persistent preference for more unified, more explanatory and simpler theories, in itself is not only a powerful reductio against standard empiricism but also a damning verdict against those realists who embrace standard empiricism and at the same time claim that they are better placed to make sense of science.

The question which therefore needs to be answered is that whether a more rational and less restrictive framework can be found which would make a better sense of science and would provide satisfactory solutions for the above fundamental problems? To answer this question we should consider three further basic and inter-related questions.

The first such question is: "What must the world be like for scientific knowledge not only to be possible but also to have the greatest chance of progress?" The second question is: "What aim and structure must science have to be successful, i.e., to give us knowledge of the observable as well as unobservable aspects of the physical universe?" And the last question is: "How must the methodology be like to maximize the success-rate of science?"

In what follows, making use of the ideas of a number of realists writers including Karl popper, Roy Bhaskar and Nicholas Maxwell, I shall try to produce satisfactory answers to the above questions. The upshot of the arguments of the paper is that a new type of realist approach, which belongs to the category of critical rationalist approach and can be dubbed 'aim-oriented empiricism', for want a better word, provides a powerful framework for not only making rational sense of science but also an effective research tradition for the advancement of science.

1. The Comprehensibility of Nature

The possibility of scientific knowledge both presupposes the intelligibility of nature and vindicates it.[1] The fact that universe is comprehensible, is indeed, as Einstein aptly put it, quite incomprehensible.[2] However, the argument for its intelligibility is not a complicated one. It is an argument from the possibility of (conjectural) empirical science: If the universe were not intelligible, science would not be possible. But science is possible. Therefore, the universe is intelligible. In a totally unintelligible universe, even if we allow for the continuation of life, improving knowledge of the universe will not be possible (*cf.* Maxwell, 1984, Ch. 9).

The above argument can at most establish the point that for science to be possible, the universe must be somehow intelligible. However, our question was: "What must the world be like for scientific knowledge not only to be possible but also to have the greatest chance of progress?" Therefore, what we should seek to clarify is that of exactly what sort of comprehensible universe will allow maximum progress for science? The intelligibility of the universe of course, can mean many, if not infinitely many, different things. The following are a number of such possible interpretations:

- 'The universe is comprehensible' means only partial comprehensibility. This thesis, in turn, can take different forms, e.g:
    * Only the phenomenal world is intelligible. The noumenal world is forever out of the reach of human beings;
    * The universe is only intelligible in certain space-time regions or under certain conditions;
    * The universe is only periodically comprehensible. There are periods of intrusion of incomprehensibility (what ever that may mean).
- The universe is comprehensible in the sense that each phenomenon, process, event, entity and thing has a guardian goddess, and only a (mystical?) unification with that goddess renders that phenomena, etc., intelligible.
- The universe is intelligible in the sense defined by occasionalists[3], i.e. direct and constant intervention of a Supreme Being enables man to see some regularities; otherwise there is no real lawfulness in the universe.

The question to be answered is that in which of these and other rival universes would science acquire its greatest chance of progress? Following N. Maxwell (1984), I will suggest that to give science the best chance of progress, it is essential to assume that the physical universe is maximally lawful (i.e. the basic structure of the universe is simple, unified, causally connected, and expressible in the language of mathematics) and maximally knowable (for the human beings). It is not difficult to reason why such a universe gives the science a better chance of flourishing (see Maxwell, 1984).

The total comprehensibility, is, from a methodological point of view, superior to other hypotheses which advocate partial comprehensibility; the chances of progress in scientific knowledge are much greater in a universe in which scientists are not barred (on priori grounds) from understanding the building blocks of that universe.

Among the partially intelligible universes two are of particular interest. One is the Humean universe in which there are no causal connections only constant conjunctions between successive events. In this universe the comprehensibility is reduced to the phenomenological comprehensibility. And the other is the quasi-Kantian universe (advocated by anti-realists like van Fraassen) in which the noumena, as posited by scientific theories, though real, nevertheless are forever out of the epistemic reach of mankind.[4]

If the universe is actually only partially comprehensible, as these hypotheses (and their ilk) would assert, a scientist who subscribes to the thesis of maximum comprehensibility of the universe will not lose anything. On the contrary, by formulating testable theories which are designed to account for the phenomena in a larger domain (as regards time & space) he will give himself a better chance of progress, in the sense of noticing his mistakes. In contrast, in the case of partial comprehensibility, there is always far greater room for ad-hoc manoeuvres which are entirely consistent with the general drive of the accepted comprehensibility assumption; any failure of the proposed conjectures for explaining the putative phenomena can be ascribed to the incomprehensibility of this particular aspect of nature rather than the shortcomings of the theory. Any particular conjecture of partial comprehensibility thesis, can therefore, not only systematically mislead scientists, but also can urge them to take a dogmatic stand, of the kind Popper has rightly criticised, towards their theories (Popper, 1971).

From the above discussion it should be clear that the proposed metaphysical picture provides scientists with a better chance of progress, in comparison to not only the metaphysical picture tacitly embraced by modern anti-realists like van Fraassen, but also to the one an entity-realist like Nancy Cartwright wants to uphold. Cartwright (1984) suggests a new metaphysical model in which different, unrelated, autonomous, parochial laws are at work. Comparing this model with the model presented above, it is clear that the chances of improving knowledge in her proposed model of universe are slimmer than the chances of improving knowledge in a universe in which it is assumed that the disparate phenomena are related by underlying simple causes[5]. In fact, even if the universe were actually exactly as Cartwright's metaphysical picture depicts, scientists will still have more chances of advancing scientific knowledge if they assume maximal comprehensibility for the universe (in the sense explained above). Heraclitus, some two and half millennia ago, has put this same point in the following way: "If you do not expect the unexpected, you will not find it." (Kasner & Newman, 1968, p. 36).

The two requirements of maximum lawfulness and maximum knowability can be translated into the following two general assumptions:

* It is assumed that physical reality (in such maximally comprehensible universe) consists of many layers or strata with different degrees of complexity, diversity and variation, of which the level of observable phenomena or appearances has the highest degree of complexity.
* It is assumed that at the most basic level of physical reality, there lies a simple, unified pattern or structure which consists of a few (possibly only one) simple entities (entity), with a small number (again possibly one) necessitating, invariant properties (property).[6] This unified pattern gives rise to all diversities and changes at the upper levels.[7] The fundamental properties of this pattern are (assumed to be) invariant through all changes, and simple (in a non-anthropomorphic sense i.e., not dependent upon our choice of languages or conceptual schemes).[8] These properties determine (probabilistically or deterministically) the precise way in which that which changes does change. The fewer the different kinds of fundamental entities and their essential properties, the more unified the 'pattern' of the ultimate physical reality.

These two characteristics combine the ideals of Heraclitus (perpetual change) and Parmenides (oneness of physical reality). History of science provides us with ample examples of such unified underlying patterns. Boscovich for example, had tried to combine the Newtonian point-particle universe with the Leibnizian conviction that force (field) is an essential property of matter. Invoking the Newtonian notion of action at a distance, Boscovich grafted it with Leibniz's view that there must be repulsive forces associated with matter to explain impenetrability. The result was a new metaphysical pattern in which the physical universe was made of point atoms surrounded by force fields which were repulsive at very small distances, attractive at very large distances, and might be alternatively attractive and repulsive at intermediate distances. For Boscovich, "force" denoted the propensity of masses to approach and recede. This picture, as we know, bears partial resemblance to the celebrated picture of interatomic forces upheld by physicists today.[9]

2. Viable Aim and Structure for Science

2.1 Metaphysics as an Essential Part of Physics

One of the major limitations imposed by standard empiricism is the claim that for science to be rational, one should not make any substantial metaphysical assumptions, about the world, or about the phenomena one is investigating. In other words, according to the conventional wisdom among those philosophers who subscribe to standard empiricism, metaphysics and science should be sharply separated. All non-empirical presuppositions, made out of necessity by scientists, must be regarded as personal preferences of individuals which have nothing to do with the main body of science proper.[10]

Some realists who are not unsympathetic towards metaphysics, have tried to square the circle by calling such principles "methodological rules". Popper for example, in his earlier writings and while his views on the role of metaphysics had not matured enough, had emphasised that: "Consistently with my attitude towards other metaphysical questions, I abstain from arguing for or against faith in the existence of regularities in our world. But I shall try to show that non-verifiability of theories is methodologically important. ... This principle ['principle of the uniformity of nature'], seems to me, expresses in a very superficial way an important methodological rule, ..." (Popper, 1934/1968, p.253; italic in original).[11]

Still other standard empiricists such as Kuhn and Lakatos, who are more sympathetic towards metaphysics and have acknowledged the role of metaphysical ideas (e.g., paradigms or hard cores) as guiding principles in developing scientific theories, nevertheless, have adhered to a model of science which allows only for a two-level structure for science, namely, level of observation (empirical evidence) and level of theory. In view of these philosophers, who do not subscribe to correspondence theory of truth, scientists' advocacy of certain metaphysical ideas, do not mean any bias in favour of certain picture of the nature of world,[12] but only a temporary acceptance of views which scientists hope to lead to further problem solving-effectiveness or more empirical adequacy. These philosophers, despite their advocacy of non-empirical assumptions about the world, do not entertain the possibility of rational theory choice on the basis of these a priori assumptions about the nature of reality. In line with their standard empiricist conviction they maintain that the fate of theories should be decided solely on empirical grounds.

The refusal of standard empiricists of allowing a priori metaphysical assumptions in deciding the fate of theories have only served to render the rational theory choice according to these methodologies impossible.[13]

However, as the discussion of the previous section showed, and as will become clearer below, the metaphysical conjectures concerning the underlying unified pattern of reality are far more significant than purely methodological or pragmatic principles. The adoption of these conjectures will set the course for all (basic) scientific inquiries. If physical reality consists of a unified, simple pattern, then the most rational way forward for the scientists to acquire knowledge about fundamental physical reality is to try to represent this unified pattern by means of a unified grand theory T, which in turn can explain all diverse, ever-changing physical phenomena in terms of few necessitating properties.[14]

In pursuing scientific research the ultimate aim of the scientists, then, should be to convert a more or less vague metaphysical theory — which states that the universe is ultimately simple, unified, coherent in the above sense — into a precise, fully articulated, empirically testable, unified scientific theory. This ultimate goal is to be pursued by progressively putting forward more and more accurate guesses concerning the nature of underlying reality and by trying to convert them into testable scientific theories (via appropriate mathematical models) with ever greater explanatory and predictive power.

Progress in theoretical science, therefore, should be understood in terms of success that is achieved in realizing the above aim. This in turn means that abandoning the standard empiricists' view concerning the relation of physics (science) and metaphysics, gives scientists a better chance for scientific progress. Far from being two separate, unrelated disciplines, metaphysical doctrines (or blueprints a la Maxwell)[15] should be regarded as integral part of grand scientific theories. Metaphysical doctrines, in this sense, are nascent scientific theories. Science therefore, should be regarded as a three-layered structure, namely, level of observation, level of scientific theories, and level of general metaphysical blueprints.[16] .

History of science can be viewed in terms of the succession of ever more unified and simpler metaphysical blueprints which have acquired the status of proper scientific theories. Kepler's favourite blueprint – that heavenly bodies move in conic sections – can be regarded as a successor to the Platonic blueprint – heavenly bodies move uniformly in circles around the earth. Keplerian theory that evolved out of his blueprint was far more precise and more successful in calculating and predicting the position and orbits of the heavenly bodies. The Newtonian blueprint offered a yet more unified, more comprehensive and simpler framework than its predecessor and when it was translated into an exact mathematical model it surpassed the Keplerian model in terms of accuracy of prediction, exactness of calculation, and comprehensiveness of scope. The same pattern was once again repeated, this time at a higher level of unification and simplicity, when Einstein developed his blueprint and produced his special and general theories of relativity out of that metaphysical framework. Einstein's blueprint and theory also unified another rival sequence of blueprints and theories, namely, the field theories, due to Faraday, Maxwell, and Hertz.[17]

2.2 Conjectural Essentialism as a Viable Framework for Scientific Theories

Science cannot rely on empiricists' or phenomenolist' aim, namely empirical adequacy. This is too impoverished an aim for science to pursue. Science must aim to capture and represent the natures or essences of the building blocks of the universe. It is only in this way that scientists can hope to acquire genuine knowledge about the physical reality. Conjectural essentialism,[18] as a general framework, will enable scientists to shape their conjectures in ways which serves the above purpose. At the heart of the conjectural essentialism lies the notion of dispositional or necessitating properties, a notion which is quite common in science.[19] These are the properties in virtue of which the entities, postulated by a theory, must, of necessity, obey the laws of the theory. It is not difficult to see that almost all – perhaps all – physical properties, both commonsensical and theoretical ones, are dispositional or necessitating. In fact if we take 'disposition' to refer to a category complementary to that of 'occurrence', such that it includes tendencies (courageous), capacities (good at playing chess), liabilities (fragile), habits (smoker), powers (waterfall's power to run a turbine), and the like (e.g. capability, potentiality, nature,...) then it is hard to see what sort of property is not expressible in terms of dispositions (Wright, 1990, p.39).

If an object (entity) has dispositional property (ies) (e.g. solidity, stickiness, electromagnetic intensity, spin, ...) then, in such and such circumstances, of necessity, the object participates in change (or resistance to change) in such and such a way. To say an object is breakable [to use an example used by Popper himself when defending the notion of dispositional properties (Popper, 1959/68)] is to say that the object is such that if it is hit by, say an iron bar, then, of necessity, it breaks. In other words, to assert that something is breakable, is to assert that that which exists can only be adequately specified by a term breakable (or its equivalent) whose meaning is such that from 'X is breakable', and 'X is hit by an iron bar'; it follows analytically necessarily, that X breaks. 'X is breakable and X is hit by an iron bar' analytically implies 'X breaks'. In other words, the property 'breakable' is such that it can only be adequately referred to by a word, such as "breakable" if the meaning of the word is such that "if a breakable object is hit it breaks" is analytically true.[20]

Our conjectures concerning the dispositional properties of the theoretical entities of course, may turn out to be wide of the mark. But this is beside the point. What is being argued here is that, these conjectures if true, are necessarily true.

An essentialistic (in the sense of conjectural essentialism) interpretation is not only available to most fundamental theories, but also can be applied to the less fundamental theories in different fields of research (e.g. physics, chemistry, biology, economics, ...).[21] Here, a certain entity with certain dispositional properties is being conjectured to be responsible for a certain repeatable phenomeon. The conjectured properties, if correct, define the nature of the entity in question and describe the ways it acts (i.e., exerts its power(s)) in statements of causal laws.[22]

Essentialistic construal of physical theories is applicable to both deterministic and probabilistic universes. If universal, invariant, deterministic, essentialistic properties do exist, then any precise true specification of the physical state of an isolated system at one instant in terms of these properties does analytically, necessarily, imply subsequent true state description. If however, we assume that the basic constituents of matter are propensitons which are governed by probabilistic rather than deterministic laws, then descriptions of the systems in terms of the their propensities give us probabilistic information about a range of possible outcomes. A specific value of a propensity P specifies n probabilities p1 ...pn and attributes a definite probability pr to each possible outcome Or, with

$$n,\text{å},r=1P_r=1.$$

Here, propensities determine how things change probabilistically in certain circumstances and parallel with the case of deterministic properties; here, there can be probabilistic necessary causal connections between successive states of affairs given that propensitons and propensities exist (see Maxwell, 1988).

Conjectural essentialism is not reducible to conditional or counter-factual statements. It is the latter which should be explained in terms of the former. For example, the counter factual statement 'If X were hit by an iron rod, X would break', is true iff X possesses the dispositional property of breakability. Likewise the distinction between 'nomic' and 'accidental' universal statements should be understood in terms of the dispositional, essentialistic properties and not vice versa.

3. A Method for Scientific Discovery

3.1 Metaphysics Once More

Standard empiricism's denial of any knowledge other than that based on empirical success imposes yet another undesired limitation on the process of knowledge-garnering; it would disparage rational investigation with regards to developing a rational logic for discovery.[23] Anti-realist empiricists like Hume, Mach, logical positivists, modern anti-realists, and realist empiricists have all rejected the idea of the possibility of a logic for scientific discovery. However, while rejection of the possibility of a 'logic of discovery' may not cause much harm for the anti-realist philosophers who define the aim of science as 'empirical adequacy, for realist philosophers who emphasise that the aim of science is to improve our knowledge of reality such rejection could produce most undesirable consequences for the success of their research programmes.

It must be emphasised at this juncture that the term a 'logic of scientific discovery', as understood by realist philosophers, does not mean a mechanical or algorithmic method which would enable scientists to run a machine and churn out more knowledge of reality. It also does not mean the reconstruction of processes which take place in brain during personal experiences of 'flashes of insight' or 'profound intuitions'. Such researches, probably fall into the realm of empirical/cognitive psychology or neurosciences. Popper for example, bearing this very point in mind, has observed that:

> I shall distinguish sharply between the process of conceiving a new idea, and the methods and results of examining it logically. As to the task of logic of knowledge – in contradistinction to the psychology of knowledge – I shall proceed on the assumption that it consists solely in investigating the methods employed in those systematic tests to which every new idea must be subjected if it is to be seriously entertained.
> Some might object that it would be more to the purpose to regard it as the business of epistemology to produce what has been called a 'rational reconstruction' of the steps that have led the scientists to a discovery – to the finding of some new truth. But the question is: what, precisely, do we want to reconstruct? If it is the processes involved in the stimulation and release of an inspiration which are to be reconstructed, then I should refuse to take it as the task of the logic of knowledge. Such processes are the concern of empirical psychology but hardly of logic (Popper, 1968, p. 31).[24]

While the opposition to the possibility of developing a 'logic' for scientific discovery may do less harm to anti-realists who, by and large, seek empirically adequate, e.g., technological knowledge, for realists who regard the central problem of epistemology to be the problem of the growth of (scientific) knowledge, it can severely jeopardise their programme.

To improve our chances of acquiring more knowledge, it is vital to seek rational means to assist the extremely important process of developing or producing new ideas and fresh conjectures concerning the nature of physical reality. In fact, if the growth of knowledge consists of constantly hitting upon new ideas (conjectures) which explain the facts in increasingly more comprehensive, unified, and simpler ways, then it seems that without making rational sense of the process of discovery, it will be impossible to provide a satisfactory explanation of the process of growth of knowledge, and therefore making rational sense of what seems to be the paradigm of human knowledge. Dogmatic rejection of the possibility of a 'logic' for scientific discovery will be harmful to both science and methodology.

It was observed earlier that a viable methodology of science should be able to assist scientists with their scientific investigations. From the above discussions it can be seen that part of the process of discovery involves informed guesses as to the natures or essences of basic or fundamental entities found in nature and hypothetically postulated in science. This notion of a rational, non-mechanical 'method of discovery', is not tantamount to the notion of a magical, infallible, all-powerful method for solving all scientific problems. It is not an alternative algorithm to replace ingenuity, flashes of insight, novelty, systematic thinking and hard empirical research. It is rather a rational method for rendering rational (as much as possible) some of seemingly non-rational processes involved in the act of discovery, and to help to bring about (in a systematic way) as much new (fallible, though corrigible) knowledge of the external world, as humanly possible.

But can such a notion be rationally justified, i.e., be shown that it is an achievable ideal? In recent years a number of philosophers of science, by invoking historical cases, have argued in favour of the possibility of a 'logic' of scientific discovery.[25] E.Zahar (1983) for example, having quoted Lakatos as claiming that heuristics belongs to some sort of limbo which is rational and non-psychologistic, goes on to add:

> I intend to show that the process of discovery is much more rational than it appears at first sight; that it is neither inductive nor largely intuitive; that it does not belong to any kind of limbo, but rests largely on deductive arguments from principles which underlie not only science and deductive metaphysics but also everyday decisions. The choices of consistent sets of such principles constitute the heuristics of research programmes (Ibid, p. 245).[26]

To understand the mechanism of a given discovery, analysis should, instead of reconstructing the psychological preconditions [as is the case with N. R. Hanson's Patterns of Discovery (Hanson, 1958)], or the sociological (in the broader sense of the term) factors [as is the case with Kuhn and sociologists of knowledge (see Kuhn, 1962)] that presumably accompany or facilitate the flashes of insight in a particular mind, be committed to reconstructing the objective situation in a science at the relevant historical moment. Such a situation in science is always characterised by a set of accepted propositions (i.e. metaphysical blue-prints) which constitute the ontology of science and set constraints as well as guidelines for its development, by logical relationships and mutual dependencies between the set's elements, by accepted epistemological values, by normative (methodological) ideals for research, and so forth.

Following Madej (*op.cit*, p. 17), we may call such situations which are responsible for the emergence of new ideas, objective discovery-generating situations. The prime role in these situations are played by basic metaphysical conjectures which act as the premises from which the construction of new theories starts and which also give rise to new sets of methodological guidelines (e.g. new sets of invariance or conservation principles).[27]

It must be emphasised however that such a 'logic', despite its plausibility, is quite under developed at present. Even among those writers who have paid attention to the role of metaphysical theories, or have sought to produce a logic of discovery, many have not bothered to introduce any preference criterion for picking up the best available metaphysical theory at a certain time, and others have at most made a hand wave at the issue, and have not produced a full treatment of it.[28]

Bearing the difficulty of the task in mind, we shall try to offer a number of criteria, which while not representing a complete and exhaustive set, are, it is hoped, on the right track and can be regarded as first steps in the direction of achieving a more comprehensible set of criteria.

In the first place, since virtually anything can act as a stimulus or motivating force for encouraging scientists to pay attention to certain phenomena rather than others, it is necessary to make a distinction between metaphysical elements which guide research and facilitate discoveries, and other non-empirical, non-metaphysical motivating forces. Because our concern in this essay is with the logic of discovery and not psychology of research, we only take into consideration those non-empirical elements which have both heuristic and constitutive values. In other words, we are only interested in the synthetic a priori assertions about the world and its constituents.

The scope of these assertions (which are to be regarded as credible candidates for scientific-theory generating blueprints) should be wide. That is to say, they should cover a large range of facts of experience. The larger the scope, the more attractive the proposal. Moreover, the coverage in question must be translatable or developable into empirically testable theories. In other words, the metaphysical assertions at stake must be amenable to mathematical modelling. This provides us with a way of testing the viability of the metaphysical proposals:

> Two different metaphysical views offer two different interpretations of a body of known facts. Each of these interpretations is developed into a scientific theory, and one of the two scientific theories is defeated in a crucial experiment. The metaphysics behind the defeated theory loses its interpretive power and is then abandoned (Agassi, 1975, pp.191-192).

Each metaphysical doctrine carves the reality in its own favoured way and introduces a number of new categories and basic entities. This fact provides us with some opportunities for rational assessment of plausibility of the suggested metaphysics. Chief among these considerations is that of whether the newly introduced ontology causes difficulties for the established theories in different disciplines which are relying on the old ontology? Or does this new ontology promote research in other fields in a smooth way consistent with the old ontology? In the former case, unless the proposed ontology is developed into a mathematically manipulatable model, it will remain of dubious value. However in the latter case, its role in further unification can be taken as a sign for its being on the right track.

The basic conservation, invariance, and symmetry principles are also of significance in deciding between rival metaphysics. If the new metaphysics, as is usually the case, is offering a new set of conservation, invariance and symmetry principles which violates the old and well established methodological rules, then it must provide satisfactory explanation as to how the old principles can be regarded as the approximate cases of the new ones. Or in cases of rejecting the old principles (e.g. rejection of parity conservation) it should show that its own new principles can better account for the evidence.

It follows form here, that if we want to understand the 'logic' of scientific discovery, we have to reconstruct various discovery-generating situations. To accomplish this task, one, of course, must recourse to historical materials. But as Madej has observed revealing the most general features of such situations, and the logical reconstruction of the passage from old to new scientific knowledge, is the job of the philosophers of science. Here, as stated earlier, Popper's methodology of 'Situational Logic' could of great help and assistance for such rational reconstructions.

Another approach for reconstructing new situations is to make use of the method of 'scenarios' based on the notion of 'possible worlds' as is customary in the field of Futures Studies. Such methods could be used as a supplementary tool within the general framework of the methodology of 'Situational Logic' (Paya, 2007b).

3.2 Changing Aims and Methods

As science progresses, it is to be expected that the aim of fundamental theoretical science will change for the better as well. Better aims are introduced for fundamental research, by progressively putting forward better and better conjectures concerning the actual unified pattern which, we conjecture, is inherent in all natural phenomena. The discovery of these fundamental patterns constitutes our aim at each stage of scientific progress. However, if the basic aims of fundamental scientific enquiry are ever changing, and if each aim requires certain methods (ways and means) for its realization / appraisal, then rationality demands that the methods and methodological rules employed in science (e.g. the rules concerning invariance, conservation, correspondence, and symmetry principles) change and develop in a fashion corresponding to the changing aims.

As our knowledge and understanding improve, our ideas about the domain of our ignorance improves, our aims improve, and so too our methods. With improving knowledge, our knowledge about how to improve our knowledge improves as well. This in turn increases our chances of error elimination and acquiring more reliable knowledge. In other words there is a continuous trade-off between metaphysical blueprints, methodological rules and our scientific knowledge. Such a promising prospect, however, is lacking in any philosophy of science which is limited to the confines of standard empiricism and adheres to fixed methods and fixed aims.

The picture which results from this way of looking at the scientific enterprise is somewhat like Laudan's reticulational model (Laudan 1984), with the fundamental difference that this reticulational structure, contrary to that of Laudan's, is being governed by one fixed aim (or if you like meta-aim), i.e. the search for the ultimate truth about the most basic physical reality. The postulation of this fundamental aim which governs the whole enterprise of science would mean that the changes in basic aims of scientific enterprise (i.e., temporary conjectures concerning the basic underlying pattern) do not result in relativism.

It should also be noted that the change in the basic aims of fundamental science is not incompatible with the stability of a number, even a large number, of lower level aims. The change in the basic aims is, somewhat, like a Kuhnian revolution whereas the stability of the lower level aims and methodological rules resembles the situation during the periods of normal science activities. However, contrary to Kuhn's conviction successive phases of scientific development (i.e. different paradigms in Kuhn's parlance) are not incommensurable.[29] A considerable degree of continuity and correspondence, is always present between successive paradigms even in cases of the most radical paradigm shift (see Post, 1971).

The changes in the symmetry, invariance and conservation principles, which are paradigms of methodological rules, can be best understood in this light: each new conjecture concerning the nature of the underlying pattern/structure of reality requires a new set of methodological principles and guidelines. In other words certain metaphysical propositions have prescriptive counterparts which can in turn be 'translated' into meta-statements about scientific hypotheses. An ontological thesis can obviously impose certain constraints/conditions on the content of scientific theories which are operating within its boundaries, i.e. ontology may be taken to have prescriptive import. It is essential that such prescriptions be translated into propositions, or rather into meta-propositions to provide methodological rules. For example, within the confines of Newtonian metaphysics which states that the physical reality consists of point particles, the corresponding meta-proposition is that all laws of nature contain only concepts of position, time, mass, and density. The methodological guide-lines are Galilean transformations, conservation of energy, angular momentum and mass, and the mirror symmetry. In contrast in the metaphysics of relativity, the corresponding meta-principle is that there is no privileged reference frame, and the methodological rules are; Lorentz transformations, and conservation of mass-energy, as well as angular momentum.

4. Critical Rationalism and Aim-oriented Empiricism

The above discussions, it is hoped, paves the way for a more viable theory of science which combines the Popperian model of Critical Rationalism with the tenets of an approach known as Aim-oriented Empiricism (or AOE for short) due to N. Maxwell (1993). This is a member of the family of meta-theories developed within the broader realist programme of critical rationalism due to Popper. We shall briefly introduce this theory and assess its promises in dealing with the problems discussed in this essay. One such problem is providing a reasonable account of verisimilitude. The other is the problem of theory choice. And a third problem is the issue of continuity and change and the possibility of progress through revolutions.

The basic tenets of AOE can be put in the following way:

1. In contrast to the majority theories of science, realist and anti-realist alike, which advocate various versions of standard empiricism and would recognize only two legitimate domains for scientific activities, namely, the domain of empirical facts and the domain of testable laws and theories, AOE maintains a third domain, namely the domain of metaphysical blueprints can be legitimately added to the proper realm of scientific activity.
2. AOE advocates the view that the basic aim for all scientific (theoretical as against technological) activities is striving towards truth, i.e., improving knowledge and understanding of the universe which is presupposed to be comprehensible. However, according to AOE, due to the changes in our metaphysical blueprints, which represent our best guesses as to how the universe is comprehensible, the aims of our fundamental theories will be in a state of change and evolution. Such changes will give rise to changing methods. It is important to appreciate that, within this framework of interconnected and changing aims, methods and theories, as our knowledge about physical reality improves, our knowledge about how to improve our knowledge also improves and thus gives us a better chance of reducing our mistakes and improving our understanding of the physical world.
3. AOE advocates the existence of a rational, non-mechanical, though fallible method of scientific discovery. This method, as discussed earlier, rests on the possibility of producing various metaphysical blueprints and developing them into fully-fledged scientific theories. The advocacy of the existence of a rational method of discovery is, of

course, based on the thesis that the comprehensibility of the universe is a part of current scientific knowledge.

4. AOE maintains that to make proper sense of scientific activities it not enough to interpret scientific theories realistically (where appropriate); it is also necessary to interpret these theories in terms of conjectural essentialism, that is to say, to regard them as attributing necessitating properties to the postulated entities. It is only in this way that one can explain why the laws of the theory are obeyed.

4.1. A Solution for the Problem of Verisimilitude

The key point in accounting for the growth of knowledge via a series of false theories, T0, T1, T2, ..., Tn, ... and arguing for the progress of science and the increasing verisimilitude of scientific theories is the notion of "approximate derivation" (see Maxwell, 1993a). If an explanatory empirically successful theory T0 is superseded by a theory T1, with greater explanatory power, empirical content, and empirical success, which explains the partial empirical success of T0, then it can be said that T0 is "approximately derivable" from T1.[30] What entitles us to regard such "derivations" as valid is that (notwithstanding the practical difficulties) it is always possible to reformulate the derivation so that T1 logically implies some T0* (some approximate version of T0).

Progress towards the truth can be viewed as a series of successive theories T0, T1, T2, ..., Tn, ... in which each term is "approximately derivable" from its succeeding term, though not vice versa. The correspondence between entities postulated by these theories can be explained in the following way. Suppose that two successive theories in the above series, Tm and Tn ($m< n$) have postulated unobservable entities Em and En respectively, and $Em \neq En$, i.e. if Tn is true (and En exist) then Em does not exist. We assume that, as we move from Ti to Ti* (as defined above) so we move from a theory Ti which postulates precise entities with precise properties, Ei, to a theory Ti* which postulates imprecise entities with imprecise properties, Em*.

As an example of this distinction between precise and imprecise entities, consider the following two versions of Newtonian theory interpreted to be about unobservable point-particles interacting by means of gravitation.

NT: point-particles have precise Newtonian gravitational charge in the sense that the particles obey precisely $F=Gm1m2/d2$.

NT* point-particles have imprecise gravitational charges in the sense that the particles obey the imprecise law $F=Gm1m2/dr$ with r is some number between 1.5 and 2.5.

Here the point-particles of NT are precise unobservable entities, whereas those of NT* are imprecise, vague, or approximate.

Granted the truth of Tn, and the existence of En, we have also that Tm* is true and that Em* exist. We can identify Em* with entities En in some special state. Suppose for example, that Tn is Atomic theory with atoms interpreted to be 'corpuscles' – entities that are indestructible and without internal parts; suppose further that Tn is the Rutherford-Bohr theory of atoms. Here Tm and Tn are incompatible. If Tn is true and atoms En exist, then corpuscles Em do not exist. Given Tm, we can however define Tm*, which asserts merely that corpuscles behave as if indestructible and without internal parts. We can 'derive' Tm* from Tn by restricting the domain of Tn to systems of atoms interacting at sufficiently low energies for the atoms to remain in the ground state. In this domain the atoms En of Tn are identical to the imprecise corpuscles Em* of Tm*.

4.2. Change and Continuity

The above account of verisimilitude furnishes us with a coherent way of looking at the problem of continuous scientific progress through changes and revolutions. The problem that has forced many realists to reconsider their realist conviction, namely, the paradox of acquiring knowledge by means of refutable and refuted theories, can be solved by AOE. According to AOE the progress of science is diachronic. It is not the case that all scientific conjectures introduce a progress in knowledge. However, in the case of successive theories which have enjoyed reasonable success, it will be possible to apply the notion of "approximate derivation" to show the continuity and smooth progress towards better understanding of physical reality. This point can be strengthened by noticing that in the case of the most radical scientific revolutions, only the top highly theoretical level will be destroyed, but the main bulk of the lower level structure of the superseded theory will be preserved, albeit occasionally under new interpretation (see Post, 1971). The retention of the explanatory content of the past successful, though refuted, theories within a restricted domain of phenomena ensures that unobservable entities approximately like those postulated by theories in question do exist. In this way, one can hold that scientific theories provide us with knowledge of unobservable world, even though they are, strictly speaking, false.

4.3. The Problem of Theory Choice

AOE's model allows scientists to break away from the straitjacket of empiricism and to invoke extra-empirical values in judging the merit of theories without rendering their own position inconsistent. From the AOE's point of view, values like simplicity, unity, and explanatory power should be taken alongside empirical adequacy, predictive power, internal consistency, and coherence in the valuation of theories. These extra-empirical and non-logical values are not pragmatic criteria, which represent the personal preferences of scientists. They are, in contrast, real (albeit conjectured) features of the physical reality which our theories try to represent. Those theories which import these features in their structures, i.e. those theories which provide a more unified, simpler view of the universe in line with their respective metaphysical blue-print and combine it with empirical success, are more likely to be on the right track than those theories which only offer empirical adequacy in an ad-hoc and cumbersome way.

Conclusion

Debates in the fields of philosophy of science and epistemology in the past few decades have greatly clarified many of the epistemic misconceptions which were hampering the steady progress towards improving knowledge of reality. For example, the powerful research programme introduced by logical positivists in the Twentieth century, despite its points of strength, was, by and large, an impediment in the path of healthy knowledge growth. While, this programme, thanks to the efforts of many philosophers of science –chief amongst them Popper and his followers, has now lost its initial hold in the academia, other types of 'positivist' tendency in various disguises are still exerting considerable influence in the academic arena world-wide. The above paper was an attempt towards further weakening the grip of such metaphysically-deprived approaches in academia. However, the task of exposing the weaknesses of less-than-satisfactory models, approaches and schools cannot be limited to empiricist and positivist modes of thinking. There are other defective approaches which are as effective in their negative role as obstacle for healthy growth of knowledge as the positivist approach. However, to deal with these other types of approaches which, on the fact of it, are poles apart from the positivist approaches but at the end, and as far as healthy growth of knowledge is concerned come to the same conclusion, we should wait for another opportune occasion.

Endnotes

1. The conjecture of comprehensibility of nature, of course, has been known to generations of philosophers. Kant (1933/1970) for example, used this principle in his so called transcendental deduction. For extended discussion of this issue and references to works of the previous generations of philosophers see Stuart Brown [ed.] (1977), pp.21-78.
2. "The most incomprehensible thing about the universe is that it is comprehensible" Einstein, quoted in Hoffmann (1972), p.18.
3. Occasionalism or parallelism is an old doctrine, introduced by some Muslim thinkers, like A. 'Ash'aree and M. Ghazzali of the eleventh century. The idea was later on revived in the West by some of Descartes' followers like A. Geulincx. Occasionalists maintained a strict dualism and denied any interaction between mind and body, which they regarded as two separate substances. They held that when a person *decides* or *will* to move his arm, it actually moves. But, his will does not *cause* his arm to move. Rather, there are two parallel series of acts going on simultaneously, one physical and the other mental. When somebody wills to move his arm, on that occasion, God moves it and thereby creates an action parallel to the person's thought. Occasionalists believed that God has decreed this and other particular parallelism from the beginning of time. See S. Stumpf (1983).
4. For a rather thorough treatment of this issue see Maxwell, *op.cit.* (1984).
5. For a critical assessment of van Fraassen's views see Paya (2004).
6. Popper (1971), in Lakatos & Musgrave (eds.).
7. Cartwright's model, as I have argued elsewhere, Paya (2000), is tailor-made to produce technological, engineering knowledge, which is less cumulative and less retrievable than the theoretical knowledge. Technological knowledge, however, when it comes to advanced technologies, is highly dependent on fundamental theoretical knowledge. In this sense, Cartwright's model cannot dispense with the full-fledged realist metaphysics.
8. Necessitating properties and essentialistic interpretations are discussed in section III.B below.
9. It needs to be emphasised that the number of layers and strata of which reality consists may well be infinite. However, scientists can, on methodological and pragmatic grounds, assume that at each stage of the

development of science there exists a (hypothetical) bottom layer with the characteristics described in the text.

10. For a discussion of the notion of simplicity in the sense advocated by realists see Post (Post 1958).
11. For Boscovich's model see L.L. Whyte (1961).
12. Standard empiricism itself is a metaphysical view. As such, rejection of metaphysics undermines it.
13. In fairness to Popper, it must be added that Popper in his later writings moved towards a more explicit position in defence of metaphysics. In this respect his position vis-à-vis metaphysics more or less resembles his attitude towards the important notion of 'Truth' where he could managed to overcome his earlier hesitation for a fully-fledged defence of this notion only after his familiarity with Tarski's theory of truth. (Popper 1976) In works like *Conjectures and Refutations* and what came afterwards Popper made two great amendments in his earlier views concerning the role and status of metaphysics. On the one hand he laid further emphasis on the continuity between metaphysics and physics (science). On the other, he differentiated between rationally criticisable and non-criticisable metaphysics. He maintained that although metaphysical systems are not open to empirical falsification, but the type of metaphysics which could be of some service to physics would definitely be criticisable.
14. Lakatos (1970, p. 15) for example, has explicitly rejected the idea that the aim of science is to progress towards the "Blueprint of the Universe". *cf.* N. Maxwell (1974). Both Kuhn and Lakatos regard 'better problem-solving ability' to be the proper aim of science and not acquiring knowledge about the reality. For Kuhn's and Lakatos' views on correspondence theory of truth see Hacking (1984).
15. N. Maxwell (1974) and D. C. Stove (1982) have shown how well-known standard empiricists like Lakatos and Kuhn have failed in making rational sense of the major problems of philosophy of science including the problem of theory-choice.
16. It must be emphasised that the unified grand theory, is not, as it is commonly and misleadingly said, "a theory of *everything*". It is only a theory which describes the most elementary constituents of matter and their interactions. The theory cannot, by itself, tell us all that is knowable about the universe. For that purpose other kinds of information are needed as well.

17. "The term 'blueprint' is used here precisely as a technical term ... to unite (or rather stands indifferently for) the two ideas "most scientifically acceptable metaphysical theory about how the world (or relevant domain of phenomena) is 'intelligible' and 'best aim for science' – two ideas that may of course be distinct for standard empiricism." (Maxwell, 1974, p.146)
18. J. Agassi (1975) also subscribes to a view not dissimilar to the above.
19. There are many studies concerning the development of different metaphysical blueprints into proper scientific theories. See for example, M. Hesse (1961), W. Berkson (1974).
20. The idea is discussed in Popper (1974), N. Maxwell (1967), (reprinted in R. Swinburne, 1974, pp.149-174), and (1993a). I have supplemented Maxwell's views with some of Harré & Madden (1975) and Bhaskar (1975/78).
21. Throughout the text I shall be using the term *disposition* on a par with the term *power*, in the following sense:
    'X has the disposition (power to) A $=_{\text{def}}$ if X is subject to stimuli or conditions of an appropriate kind, then X will A, in virtue of its intrinsic nature (which may well be – at the sufficiently basic levels – identical with the disposition'.
    Popper is one of the few the non-positivist philosophers in this century who has advocated the notion of dispositional properties. However, as we shall see in the text, despite his largely valid observations, his model suffers from certain shortcomings. For Popper's discussion of the dispositional properties see his (1959/68), appendix *X, and his (1963) *passim*. A. Wright (1990, pp.39,41) reports that modern major writers have by and large neglected the important issue of dispositional properties and have failed to address themselves to this topic. 'The exceptions are Ryle (1949), Goodman (1955), Carnap (1956), Popper (1959/68) and Quine (1960) who, save Popper, were all against the notion of dispositional properties. Such a negligence on the part of philosophers, as Wright points out undermine any putative attack on empiricism in that it promote the notion of 'event' to the primary epistemological position at the expense of interlinked notions of 'thing-kind' and 'disposition'.

In recent years, probably since 1970s, the idea of dispositional properties has become more fashionable amongst philosopher of science. Even an avowedly empiricist philosopher of science like Nancy Cartwright in her recent works has tried to persuade fellow empiricists that why they should embrace notions such as capacity and disposition. See Cartwright (1989). A. Wright (1991) has produced a list of some of the more recent advocates of notions such as disposition.

22. It is important to appreciate that the notion of dispositional properties introduced here amounts to an ontic necessity as opposed to accidental generalization: an object may break in many occasions that it is hit by an iron bar, and yet it may not be breakable in the ontic sense of the word. The ontic necessity, as indicated above, when translated into *words*, takes the *form* of analytic necessity: It is true by virtue of the very meaning assigned to it, in the same manner that 'All triangles have three sides' is true analytically. This however does not mean the re-appearance of the undesired linguistic essentialism from the back door. The necessity at issue stems from the very fact that the real structure of the object is such that it is necessarily breakable.
23. Cartwright (1989) seems to be in favour of this type of essentialistic theories with limited range of applicability. However, the view which tries to relate these theories to even more general, more fundamental, and more covering theories, as we have argued, gives the scientists a better chance of progress.
24. This point has been discussed by Harré (1973), Harré & Madden (1975), and Bhaskar (1975/78).
25. Standard empiricism has encouraged its subscribers to draw a sharp distinction between the so-called context of justification and context of discovery. This distinction almost by definition pushes all talks about rational assessment of the process of discovery, including the possible ways of constructing of a logic for scientific discovery, to the realm of psychology of research and thereby inhibits, from the outset, attempts for developing such a logic.
26. In the light of the above it is important to note that Popper deliberately chose the English title of his *Opus Magnus*, 'The Logic of Scientific Discovery' whereas the strict English translation of the original German title, namely, *Logisch der Forschung* is 'Logic of Research or Investigation'. It seems popper intended to emphasis the very point he has made in the above quotation, namely, the need to distinguish between what is the task of empirical psychology and what is the responsibility of a philosopher of science when it comes to the issue of a 'Logic of Scientific Discovery'. Popper in some of his other writings

where he discusses his idea of the 'Situational Logic' as a methodology for social sciences and humanities explains what does he mean by 'logical reconstruction' of a situation. He emphasises that this process is different from 'empathy' in that it consists of objective conjectures concerning the behaviour of the subjects and not the impossible task of trying to place one in the shoes of the subjects. See, Popper (1994), Paya (2003, 2006b, 2007).

27. One may cite Hadamard's *The Psychology of Invention in the Mathematical Field* (1945) and Polya's *How To Solve It* (1945) as two of the earliest systematic attempts on the study of the methods and rules of discovery and invention. The only limitation of these otherwise inspiring books may be that they only deal with examples drawn from mathematics.
In recent years a larger number of writers have tried to show the untenability and undesirability of the sharp distinction between the so called context of discovery and context of justification. These writers, by and large and to various degrees of thoroughness have argued that a *logic* of scientific discovery is both legitimate and possible. See G. Gutting (1968), G. Holton (1986), E. Zahar (1983), R. Bhaskar (1978), N. Maxwell (1991 & 1992) and A. Miller (1992). See also E.Pietruska-Madej (1985, pp.7-18) for a similar position, though with less argumentation. Further insights and arguments can be found in the two following anthologies M. D. Grmek et.al. [eds.] (1977), T. Nickles [ed.] (1980).

28. Zahar, as the above quotation indicates is in favour of a deductive logic for discovery. There are other writers who would make use of inductive reasoning as well. See for example, Bhaskar (1978). However, as Popper has argued at length in many of his publications, inductive reasoning is not a valid mode of reasoning in the realm of empirical sciences. This means that, realists like Bhaskar should try to translate the insights of their models into proper deductive modes of reasoning.

29. To construct the required situation the researcher can also benefit from the methodology of 'Situational Logic' proposed by Popper for (mostly) human and social sciences. See, Popper (1994), Paya (2004, 2006b, 2007).

30. An exception, is N. Maxwell (1993), part II.

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