Science and Modern Cosmology*

Herbert Dingle
University College, London

IT has become the custom in recent years for the president, during his term of office, to address the society on the department of astronomy in which his own work lies. It is a good custom, but not one which at first sight it seems possible for me to maintain. My subject is the history and philosophy of science, and that can scarcely be called a department of astronomy; it seems either to lie wholly outside or else to include astronomy as a small part of its concern. In neither case does its claim to your interest on this occasion seem a strong one. Nevertheless, I believe that it is in fact highly relevant to the present position in astronomy. Had that not been so, I should not have been justified in accepting the high office to which you called me 2 years ago. I propose therefore to explain as best I can why I think this subject is vitally pertinent to the working astronomer of this age.

Of course, in one sense the study of the history and philosophy of science needs no apology in any sphere. Science plays such an essential part in modern life, on both its active and its contemplative sides, that no one can call himself educated who has not some idea of its nature and its history. That I think is indisputable, but it is not so clear that a knowledge of these things is necessary to the actual prosecution of astronomical studies. Science has been advanced in the past by men who have paid little attention to the wider implications of their actions, men who would have been unable to formulate any clear statement of what they were doing, and whose knowledge of the origin and growth of science has been negligible. They have gone forward in the right direction as though by instinct, seeing spontaneously what is legitimate and what is not. And such men have not been exceptional among scientists; they have been typical. It is not surprising, therefore, though it is regrettable, that there are many even today who hold that the scientist and the philosopher of science are pursuing independent ends, and the less they interact, the better for the progress of science.

The apparent justification for this view lies, I think, in the peculiar nature of science by which in its earlier stages it has automatically generated within itself its own steering mechanism, so to speak. In the first place, the world has been so full of mysterious phenomena that there has been no temptation to wander outside experience in search of other realms to conquer; and second, it has become almost an intuition with scientists that they must submit their findings to the test of observation at every stage. If a scientist tends to postpone this duty, his neighbor, who holds different views, has always been at hand to perform it for him. Science has thus stood in little danger of violating its own essential principles, and the understanding of what those principles are has been, from the practical point of view, a superfluity. But this state of innocence no longer exists. In cosmology in particular it has almost entirely disappeared. The universe we contemplate today is no longer the observable world that for 2000 years was the sole object of astronomical study; it is a hypothetical entity of which what we can observe is an almost negligible part. The assertions we make about it, if susceptible of test at all, require observation over periods of millions of years or in the remote past and are, therefore, beyond any sort of practical check. In these circumstances, there is nothing that can control speculation, and preserve legitimate theory from idle fancy, but a strict adherence to the essential principles of science, those principles that in the 17th century started the course of ever accelerated progress by which the scientific philosophy is most obviously distinguished from the philosophies that were then its rivals.

In cosmological studies, then, a knowledge of the history and philosophy of science is not a superfluity; it is a necessity. I therefore make no apology for asking you to consider its bearing on the recent revival of interest in this most ancient branch of our subject. I do so the more readily because, although some of the prominent contributors to modern cosmology have unconsciously realized that the nature of science has some special relevance to their researches—witness their frequent appeals to what is "scientific" and what is not, which are not a normal feature of astronomical papers—they betray not only a profound ignorance of the subject but also a clear lack of any serious reflection on what they are saying. It is as though—as, in fact, I believe to be the case—they are not really concerned to know whether they are being scientific or not but wish to dignify their own opinions, and discredit opposing ones, by invoking a name that commands general respect. Let me take two examples.

"It is against the spirit of scientific inquiry," says one writer (*1*), "to regard observable effects as arising from 'causes unknown to science,' and this in principle is what creation-in-the-past implies." There are more than one astonishing aspects of this remark. For instance, what conceivable misfortune could have led the writer so to misinterpret both the words and the performances of almost all the great contributors to science as to think that a confession of ignorance is "unscientific," when in fact one of the chief characteristics of the scientific attitude has always been just that particular type of humility. Galileo recommends his readers "to pronounce that wise, ingenious and modest sentence, 'I do not know' " (*2*). "The cause of gravity," wrote Newton, "is what I do not pretend to know" (*3*). And again (*4*)

> . . . to derive two or three general Principles of Motion from Phaenomena, and afterwards to tell us how the properties and actions of all corporeal things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discover'd: And therefore I scruple not to propose the Principles of Motion above-mention'd, they being of very general Extent, and leave their Causes to be found out.

I refrain from running through the centuries to cite confirmatory evidence, because I must mention a still more astonishing thing. After making this unfortunate remark, the writer proceeds to develop his own idea, which turns out to be precisely what he has just opposed to the spirit of scientific inquiry—namely, that the observable universe was created in the past by causes unknown to science. The natural inference is that he is averse from scientific inquiry and is arguing for a more excellent way, but I do not think that this is the true explanation. I believe that he has a vague feeling that he can confer some dignity on his theory if he can stigmatize alternatives as "unscientific," and without reflecting on what science really is, or on the obvious implications of his own remark, he presses its name into his service for that end.

I pass to my second example. "Experimental science," we read (*5*), "is based on the assumption that the repetition of an experiment will reproduce the original results, and indeed the realm of experimental science is defined by this criterion." And again, elsewhere, to emphasize the point: "The unrestricted repeatability of all experiments is the fundamental axiom of physical science" (*6*). The first thing to notice about this is that experimental science is said to be based on an assumption. It is based on no assumption; it is an adventure, in which you accept whatever you find, and although you may be guided in a particular case by an expectation, the experiment may reveal something totally different. Schwabe counted sunspots with the idea of finding an intra-Mercurial planet; instead he found the 11-year solar period, and he would have found exactly the same had he counted the spots with any other object in view, or with none. Does anyone believe that if tomorrow it is discovered that some assumption—any one you like—which has been made in the past is baseless, the achievements of experimental science will suddenly lose all significance? I do not think so. The "fundamental axiom" goes wrong at the very beginning. But not only is it not the basis of science; it is patently false and could not be the basis of anything worthy of acceptance. The most striking example of this is afforded by psychology. It would scarcely be wrong to say that in this science—the emergence of which in recent years is one of the most striking relevations of the great scope of the scientific philosophy—there is no experiment which, when repeated, produces the original result (*7*). It would be difficult to conceive of a more crippling restriction on the liberty of modern scientific inquiry than the adoption of this supposed fundamental axiom. But, indeed, one need not go to psychology for evidence. Even in physics, where the writers might have been expected to be more widely informed, it has been the universal belief for the last hundred years that no experiment is repeatable, the entropy of the universe never being twice the same. It can hardly be objected that the universe is irrelevant, because it is precisely to the universe that the supposed axiom is later to be applied, but even on the small scale there are sufficient examples of hysteresis phenomena to have shown the falsity of such a notion to anyone who had stopped to think for a moment. Two apparently indistinguishable pieces of iron are subjected to the same magnetic field and they respond differently; and the explanation that science gives is that one has been through the process before and repetition gives a different result. In the circumstances it is perhaps not superfluous to say that if it is contended that the pieces of iron are really different, but only appear alike, the whole argument becomes circular. The reason why so many experiments are approximately repeatable is that we take infinite pains to select them from the others, because in the earlier stages of science, in which we are at present, they are easier to interpret than the great majority of possible ones which are scarcely ever repeatable. Our cosmologists have mistaken a common-sense device for an essential principle.

Now I have not given these examples merely to show that the name of science is treated with a casual disrespect unworthy of serious investigators. If that were all they could be ignored. But the position is much worse than that. This last illusion is not merely a casual aside. It is made the basis, and the sole basis, of a sweeping assertion which has been called "the perfect cosmological principle," for which, with its companion, "the cosmological principle," enormous claims are made. For example, the cosmological principle has attained the "pre-eminent position in cosmology" (*8*), and "In any conflict between general relativity and the cosmological principle it seems that it is general relativity that must be abandoned" (*8*, p. 122); while at the behest of the perfect cosmological principle atoms are created and nebulae vanish from the observable universe. The "cosmological principle," I should explain, is the assertion that "the universe presents the same aspect from every point except for local irregularities" (*8*, p. 11), and the "perfect cosmological principle" states that "apart from local irregularities the universe presents the same aspect from any place at any time" (*8*, p. 12). If we ask for evidence for these principles, of the kind that can be accepted as scientific, we see that for the "cosmological principle" there is the fact that so far as the universe has been surveyed—which is probably a very small fraction of its whole extent—there is a rough approximation to uniformity of distribution of matter. This makes it reasonable to assume, for purposes of investigation, that a similar uniformity might characterize the whole, in anticipation of the time when we can compare the implications of the assumption with the wider knowledge that will later become available. For the "perfect cosmological principle," on the other hand, there is no evidence of any kind at all. Since it causes me considerable discomfort to use names which are clearly misleading, I shall refer to the "cosmological principle" as the *cosmological assumption* and to the "perfect cosmological principle" as the *cosmological presumption,* reserving the right, when the "absolutely perfect cosmological principle" makes its appearance, to introduce the terms *first* and *second* cosmological presumption.

Now we have here a remarkable and a very serious phenomenon. I have no time to discuss the meaning of science, so I will here assert of it only that which I think will command universal assent, namely, that *no statement about the universe, or nature, or experience, or whatever term you prefer for the object of scientific investigation* (*9*) *shall be made*—let alone advanced as a fundamental principle—*for which there is no evidence.* What we are faced with now is the quite different claim that *any statement may be made about it that cannot immediately be refuted.* It seems that if you are attracted by an idea for which there is no evidence, all you have to do is to call it a "principle," and then no evidence is needed. We are told that matter is being continually created, but in such a way that the process is imperceptible (*8,* p. 143)—that is, the statement cannot be disproved. When we ask why we should believe this, the answer is that the "perfect cosmological principle" requires it. And when we ask why we should accept this "principle," the answer is that the fundamental axiom of science requires it. This we have seen to be false, and the only other answer that one can gather is that the "principle" must be true because it seems fitting to the people who assert it. With all respect, I find this inadequate.

I want to trace the steps by which it has become possible for what is in fact the contrary of science to present itself as something essentially scientific, and not to be immediately recognized in its true form, but before attempting this I must call attention to another example of the same disconcerting phenomenon, for both will be found to spring ultimately from the same source. I said that in true science nothing is asserted without evidence. I can go a step further, without challenge from any authority of whom I have ever heard, and say that the object of scientific investigation is the world of experience—or, if you like, experience itself—and that all advances in science consist either in enlarging the range of experience or in expressing the regularities found or to be found in it. The new doctrine which I have so far been discussing arises from the substitution for the phrase "expressing the regularities found in experience" of the incompatible phrase "asserting that experience must conform to the tastes of the investigator"; and the other doctrine, which is its twin, arises from the substitution of the phrase "asserting that experience must conform to a pattern which we can deduce by pure reason." This also has been used to build up an elaborate scheme of cosmology (*10*), and it deserves a little closer examination before we seek to discover how it came to intrude into the scientific domain.

This doctrine is usually expressed in the form that the laws of nature can be derived by reason without recourse to experience (*11*). What those who assert it seem to overlook is that, by definition, laws of *nature* are laws followed by that which we experience, not that which we deduce from our axioms. It is therefore self-contradictory to say that laws of nature can be derived without recourse to experience: it is like saying that eggs can be eaten without recourse to eggs. What seems to be meant is that there are some objectively existing mathematical formulas called "laws of nature" which we can arrive at by a process of reasoning, and then, if we look at the world, we shall find that it behaves according to those laws. But suppose it does not, as even the simplest of us may imagine? Only one of the believers in this doctrine, so far as I know, has attempted to answer this question, and his answer is that in that case we must have made a faulty identification between the *a priori* laws and the corresponding facts of nature (*12*). But this leaves us no means of knowing when we have made the right identification except by an appeal to experience, so we are back at empirical science again; we can derive laws of nature without recourse to experience, but we cannot know that they are laws of nature without recourse to experience.

The fact is that nothing at all can be derived by reason unless you start with certain axioms which in the last resort must be chosen arbitrarily (*13*). Take what seem to be the most obviously necessary of *a priori* truths—the rules of simple arithmetic. Nothing would seem more clearly a truth derived by pure reason than the statement $1-1=0$, and to this, if to anything, we might expect experience inevitably to conform. But does it? In some things, yes, and in others, no. If you take from me my only sixpence, I have none left; the law is inexorable with regard to sixpences. But if you take from me my only idea, you are (let us hope) enriched, but I am not impoverished; I may even acquire another idea in the process; $1-1=$ at least 1 in that case. The statement $1-1=0$ is a truth derivable from certain axioms about numbers, and from other axioms you can derive other conclusions, which you can call "laws of nature" if you wish and which are equally necessary deductions from the premises. But the scientific question is not whether you can derive such laws about the universe, but "Is the universe the sort of thing that obeys those laws or is it not?" You can answer that only by observing it to see.

We have, then, the strange position that in cosmology two impostors have usurped the throne of science, worn her crown, and taken her name. Whereas the source and final court of appeal in science is experience, that of one impostor is personal taste, and that of the other, pure reason. Neither is, of course, new: it was one of the triumphs of the scientific philosophy in the 17th century to have apparently routed them both.

But they differ in this respect, that the former has never before, to my knowledge, presented itself quite so brazenly as a genuine philosophy; it has always worn a disguise showing a more respectable aspect. How has it come about that at this relatively advanced stage in the progress of science these pseudo-sciences have again come to life and threaten to deceive the very elect?

I think the process began with the advent of the theory of relativity. This is ironical, for the essence of that theory lay in the recall of science to experience from which it had unconsciously strayed. Nevertheless, I think we can see how the thing happened. As everyone knows, the solution of certain problems which faced classical physics was found to lie in the fact that some concepts—the absolute simultaneity of separated events is perhaps the best-known example—had been assumed to be directly related to experience, whereas in fact they were not. On examination it proved that by no physical process was it possible to determine unambiguously whether two such events occurred at the same time or not. Accordingly, in order to establish science on its proper basis—that of experience—such concepts as these were eliminated and experience was described in terms of those concepts alone which had a precise empirical meaning.

The particular error which was thus corrected happened to arise from incomplete consideration of the effects of changing one's coordinate system. Now a coordinate system is an invention of the scientist which facilitates the expression of the regularities which he finds in experience. It is not itself something found in experience; it is a purely imaginary construction which some scientists have tried to do without, but which nevertheless has become firmly established as a part of the physicist's language, so to speak. Before describing physical events it is convenient to choose one particular point in space and one particular instant in time, and to assign to them the number 0. The point-event thus defined is called the *origin* of coordinates. Next, three mutually perpendicular lines (or something equivalent) are imagined to extend indefinitely far, each in both directions, from the origin. These are termed the *axes* of coordinates. They are graduated in any arbitrary way, provided that the graduation numbers increase numerically outward from the origin in all directions; and the successive instants of time are enumerated in any arbitrary way, provided that the later of any two instants has an algebraically higher number than the earlier. Finally, the whole system of coordinates is assumed to be moving with some velocity v in some direction. Now every element of this coordinate system—the origin, axes, graduation, velocity—is arbitrary, to be chosen as the investigator thinks convenient. It is a fiction, a language in terms of which to express what is observed to happen, but it is itself not something that exists or happens, not a part of the universe or an element of experience. It follows that you can change it as you wish, without affecting in any way at all what is to be described in terms of it, but of course changing the description, just as you do not change the meaning of a sentence when you translate it from English into French, although you change the sounds uttered or the marks made on paper.

Because of this essential arbitrariness it becomes important to understand how to translate descriptions of experience from the terms of one coordinate system into those of another, for only thus can you distinguish, in a particular expression of the laws of nature, what part belongs to the world described and what merely to the language of description. The essence of the theory of relativity consisted in the discovery that it had been wrongly assumed in the past that one particular set of coordinate systems had a unique importance in that it was not, like the others, merely more convenient than its rivals, but was itself a part of nature. All efforts to discover this unique set had failed, said the theory of relativity, because there was nothing to discover, and to safeguard future investigators from making the same error it employed a particular mathematical device, known as the tensor calculus, which automatically insured that laws of nature expressed in terms of it were exactly translatable from any one coordinate system into any other. From that time onward it became the fashion to seek a tensor expression for all laws of nature. Indeed, in some respects the thing was overdone, for while it is true that tensor expressions insure that no coordinate system has preferential treatment, they are not necessarily alone in this, and a proposed law of nature is therefore not necessarily invalid if it is not in tensor form. That, however, is a minor point. The essential thing is that by means of the tensor calculus we can avoid the mistake of ascribing to nature what actually belongs only to the arbitrary machinery for describing nature.

In carrying out the program thus set up, Einstein arrived at what have been called his "field equations"; they are as follows:

$$G_{\mu}^{\nu} - \tfrac{1}{2} g_{\mu}^{\nu} G = -8\pi T_{\mu}^{\nu}.$$

These are expressions in tensor form of certain regularities found in nature by experiment. The distinction between the expression and what is expressed is perfectly clear. On the right-hand side of the equations you have the relations which have been found by experience to hold between measured quantities. These could have been derived in no other way than by observation; they are direct statements of the results of observation, and as such are independent of any freedom of choice which the scientist may possess—other than that of refraining from making or examining the measurements, of course. On the left-hand side of the equations you have the expression of these relations in terms of coordinates, and by choosing a tensor expression you insure that if it holds good in one it will hold good in all such systems, whatever they may be. The observer's liberty is thus wholly confined to the left-hand side, and it is subject only, but inescapably, to the condition that his tensor must in fact express the observations given on the right-hand side. In general, there are a number of tensors that will do this.

Pending further knowledge, the observer then chooses the simplest and, if he is wise, remembers that his choice may be wrong. This is what Einstein did, and the essential condition of science was thus preserved. The findings of experience stand first of all in their own right, and the mechanism of description is then chosen with complete freedom so long as that right is not violated. This is known as the general theory of relativity.

At this point it becomes possible to apply the theory to the universe. The first step is to observe the universe and see how it behaves; the second, to find tensors whose mathematical properties correspond to that behavior. Unfortunately, the first step is possible only in the most rudimentary form. We can observe a little of the region nearest to us; of what lies beyond we know nothing. It is necessary, therefore, if we are to consider the matter at all, to make some assumptions. Einstein assumed that the universe was homogeneous; that is to say, that the region we can observe is a typical sample of the whole. He recognized, of course, that this was an assumption, but the other possibilities were so numerous that it was impossible to choose between them otherwise than by pure caprice, so the assumption of homogeneity was made to see what it would yield. The field equations could then be used to deduce what happened at the places and times corresponding to high values of the coordinates, at present beyond the reach of observation. The deductions would be valid, subject to two conditions: first, that the universe was, in fact, homogeneous, and second, that the tensor chosen for the left-hand side of the equations was, in fact, the right one, so that extrapolation could be made with safety.

I need not describe how Einstein's original model for the universe came to be modified when the systematic recession of the nebulae was discovered, because this introduced no change of principle. What I am seeking is the process by which this essentially scientific procedure became degraded into unscientific romanticizing. I think the first step on the slippery slope was taken when, in the spate of popular expositions of relativity that followed the eclipse observations of 1919, a coordinate system—a somewhat abstruse mathematical conception—was transformed into an "observer," whom the general reader was presumed to be able to picture much more vividly. Instead of comparing two coordinate systems which were equally at the choice of a single observer, two observers were compared, each of whom was supposed to regard himself as being at rest at the origin of his own unique system. I do not think that those who adopted this device can be blamed for its consequences. It is certainly more picturesque than the naked truth, and, provided that the hypothetical observer is granted no properties that are not possessed by a coordinate system, it is quite legitimate. The expositors could scarcely have foreseen that the coordinate system was soon to be endowed with a mind, with superhuman observing faculties, and with authority to dictate to the poor working scientist what kind of instrument he must restrict himself to and how he must adjust it. But that, in fact, is what happened. In the theory of kinematical relativity (*14*) we do not start with observation; we start with a universe full of supposititious observers who must not only be able to construct instruments but must voluntarily choose particular numerical constants—that is, they must be thinking beings, not merely mechanisms. These observers are essential to the existence of science, for they are necessary to the construction of all measuring instruments; unless they exist and behave in the way laid down for them, science cannot begin. The mere fact that it has begun without their assistance is ignored. The instruments we have in fact used are proscribed because, it is said, they cannot be "defined." The beautifully clear-cut division that relativity made explicit between the world to be observed and described on the one hand, and the coordinate language in which to describe it on the other, is completely obliterated. The coordinate language is transformed into a multitude of intelligences and projected out into the world to be observed. We do not in fact observe them, but that does not matter, for we have already decided how they behave. Our part is to restrict our operations to those which they approve, and the rest of the universe must be such that they all agree about it. If it appears to us to be different from that, so much the worse for us; our observing instruments must be illegitimate, and no account must be taken of their findings.

This seems a long way from the scientific ideal of accepting observations without question and reducing them to order by the free operation of reason, but I think we can see how it has happened. It is true that general relativity made a sharp distinction between the world to be observed and the coordinate systems of our invention, but that distinction was very different from what had previously been supposed. Scientists had long been accustomed to choosing the origin and axes of their coordinate system when and where they liked, but they had always supposed that its motion was not at their choice; it belonged to the world outside. Relativity showed that that was not so, that just as it was impossible to say that one particular place and time afforded the only legitimate observation point, so it was impossible to say that one particular state of motion was so distinguished. A great deal, therefore, of what had previously been thought to belong to nature was shown to belong really to ourselves. Figuratively speaking, Einstein's field equations could be said to have been formed out of their predecessors by a huge transfer of substance from the right- to the left-hand side. This sudden accession of importance to the coordinate system predisposed mathematical physicists to invest it with still greater importance, and its personification as an "observer" pointed the direction of development. It was automatically animated and given rights of its own which the actual observer was not allowed to violate. His instrument thus became a Frankenstein's monster, slipped from his control, and began to dictate to him what he should observe. And this was done in the name of relativity (*15*). It was completely overlooked that the justification for Einstein's action lay in the fact that no physical effects of motion in itself, of "absolute" motion as it is called, were discoverable and that its transfer from nature to the coordinate system was therefore a simple expression of fact. To satisfy the demands of the hypothetical observers, *relative* motion also was transferred to the coordinate system, although the effects of this were observed every day. All that was necessary was to call the time of occurrence of these effects by the symbol τ instead of t, and the thing was done. The imaginary observers were in complete control, and science, its name having been purloined, was left as an outmoded superstition.

It is now but a step to the advent of the second of our two usurpers. The whole foundation of kinematical relativity lies in the existence and potentialities of the army of cosmic observers. They must therefore be established on an unshakable basis. They are certainly not observed; hence they must be either imagined or reasoned into existence. Imagination had not then become sufficiently respectable as a basis for cosmology—that was to be reserved for the creators of the cosmological presumption—so it was held that the cosmic observers were required by pure reason. A universe that did not conform to the behavior prescribed for them was held to be irrational. This universe is not irrational. From this the whole scheme followed, with far-reaching consequences, not only astronomical but even theological (*10*).

It is very difficult to describe this work objectively without giving an impression of satire, but I have no intention whatever of doing so. I have the extremest admiration for the single-minded devotion and superlative mathematical skill which are evident throughout the development of this grandiose scheme, but I find it impossible to describe it in the light of the accepted principles of science without making it appear fantastic. And the reason is simply that it is fantastic. Repeated attempts to call attention to what appears as its fallacies have been futile. They have never been answered, but have simply been dismissed as "trivial" or even "frivolous" (*16*). No criticism has been admitted as valid that is not a criticism of the internal consistency of the scheme. The status of its foundations, and its relevance to the traditional object of scientific inquiry, the world of experience, are held to be idle questions. I can only do my best to present it in the clearest possible light against the scientific background, and leave it to be judged in that setting.

I return now to the other violation of science in modern cosmology—that which originated in the cosmological presumption. This also was made possible by the revolution in thought caused by the general relativity theory, and its point of departure is again the wide scope shown to be possessed by coordinate systems. Let me point out once more the fundamental distinction which general relativity acknowledged and emphasized between coordinate systems, which are entirely subjective, entirely under our control, and entirely independent of the universe which they are employed to describe, and the universe itself, which is entirely objective, not in the least degree under our control, and remains precisely the same whatever coordinate system we employ for describing it. Kinematical relativity made the error of personifying coordinate systems and so endowing them with properties that could properly belong only to the objective universe. The cosmological presumption made the opposite error. It transferred to the universe the wider characteristics which relativity had found to belong to coordinate systems. Because coordinate systems, being pure fictions, were all precisely equivalent so far as objective validity was concerned, the cosmological presumption declared that *all aspects of the universe* must be precisely equivalent also. It is like saying that because all languages are equally valid for stating the propositions of Euclid, therefore all the propositions of Euclid must be equivalent to one another. The essential distinction between the objective world on the one hand and the rational observer of it on the other, which, I repeat, has always been fundamental in science and which relativity restored and reformulated, is here again destroyed, and a purely imaginary characteristic is foisted on the universe and presented as a basic axiom of science to which general relativity must yield place.

The next step is obvious. The appearance of the universe must remain the same. But observation seems to show that the universe is scattering apart. Therefore matter must be in process of creation all the time, at such a rate as to compensate for that which recedes from observation. This consequence of the presumption has proved specially attractive, for it has given rise to an alternative scheme in which it is itself taken as a fundamental postulate, without even the support of the baseless cosmological presumption. In this variant of the "new cosmology," as it has been called, and as I will for convenience call it here since it is not literally inaccurate, it is simply asserted as a primary axiom that matter is continually being created (*1*). Something akin to the cosmological presumption then follows by the reverse process of reasoning, for the rate of creation is guessed as being just that at which matter disappears by recession; hence the general aspect of the universe remains the same at all times This is said to conform to the principle of the field equations of general relativity, for you have simply to make a slight change in the tensor on the left-hand side, and the right-hand side will then describe a universe in which creation takes place continually.

I am here again faced with the difficulty that I cannot give a true account of this new cosmology without appearing to ridicule it. I am doing nothing of the kind. I am simply divesting it of the symbolic clothing in which it has been wrapped for formal presentation, and the substance underneath appears ridiculous because it is ridiculous. It is hard for those unacquainted with the mathematics of the subject, and trained in the scientific tradition, to credit that the elementary principles of science are being so openly outraged as they are here. One naturally inclines to think that the idea of the continual creation of matter has somewhow emerged from mathematical discussion based on scientific observation, and that, whether right or wrong, it is a legitimate inference from what we know. It is nothing of the kind, and it is necessary that that should be clearly understood. It has no other basis than the fancy of a few mathematicians who think how nice it would be if the world were made that way. The mathematics *follows* the fancy, not precedes it; the fancy is credited because it gives scope for mathematical exercise, not because there is any reason to believe it true. Here are the actual words of one of the originators of the scheme (*8*, pp. 95–96):

> Equation (10.5) [Einstein's field equations] may be read either from left to right, showing how the presence of matter affects the geometry, or from right to left, showing how the density, momentum and energy of matter must satisfy the well known conservation laws owing to their relation to geometrical quantities which are automatically conserved.

Remembering what the two sides of the equations mean, we see that what is here asserted is this: we can either observe how the universe behaves and choose a tensor that describes the observed behavior, or we can construct a tensor having whatever properties we like and infer that the universe behaves accordingly. And, in fact, this second alternative is the one chosen in this second form of the new cosmology. A tensor is invented whose divergence does not vanish. This is substituted for the left-hand side of Einstein's field equations, and the divergence of the right-hand side must therefore also not vanish. The right-hand side describes the observable behavior of the universe. Hence the universe must be such that matter is continually being created in it.

How is it, we may well ask, that such a thing is possible after three centuries of scientific progress in which it has over and over again been exemplified that the speculations of even the most gifted of seers go far astray from the reality that observation is to reveal? The question is a psychological one, of course, but it is not out of place to ask it here, for the answer may help us to understand still more clearly what value to place on these chimeras. So far as I can judge, the authors of this new cosmology are primarily concerned about the great difficulty which must face all systems that contemplate a changing universe —namely, how can we conceive it to have begun? They are not content to leave this question unanswered until further knowledge comes; all problems must be solved now. Nor, for some reason, are they content to suppose that at some period in the distant past something happened that does not continually happen now. It seems to them better to suppose that there was no beginning and will be no ending to the material universe, and therefore, tacitly assuming that the universe must conform to their tastes, they declare that this must have been the case.

But if we must really answer all questions immediately, is their solution in fact more intellectually satisfying than that of a special creation? Consider what it implies. Granting for the sake of argument that the nebular red-shift indicates that nebulae are continually receding into inaccessibility by surpassing the speed of light, we are then asked to believe that isolated fundamental particles are continually created within the accessible region in order to maintain the same total quantity of observable matter at all times. One immediately looks for a connection between these two processes. We are led, for instance, to suppose that when a nebula reaches the speed of light its particles might undergo a number of gigantic quantum jumps back into the observable region, something like those pictured in Bohr's original theory of spectra. But this appears impossible, for a nebula, on reaching the speed of light for us, is still observable from another nebula not so far distant in the same direction, and the process would have been observable there before becoming knowable to us. Hence the sudden vanishing of nebulae moving at relatively slow speeds should be observable from one nebula, and therefore from all. No such phenomenon, however, is postulated in the scheme. It seems, therefore, that the recession of nebulae into unobservability and the creation of particles relatively near at hand must be independent processes. Yet they occur at exactly the same rate —not approximately, but exactly, for the universe must appear the same eternally—eternally in the past and eternally in the future. Such an extreme example of pre-established harmony—if the new cosmologists will forgive the phrase for what they will perhaps regard as an accident—is, to my mind at least, harder to credit than a special creation in the past. If I must choose I choose the latter as the less revolting to common sense, but on the whole I prefer that wise, ingenious and modest sentence, "I do not know."

I cannot help wondering what would happen if the new cosmologists turned their attention to biology, for here there is a very similar problem. We observe living matter and dead matter, but we never experience the creation of living matter out of dead matter alone. We seem here to be faced with the same two possibilities as in cosmology: we can suppose either that, at some epoch in the past, dead matter somehow became alive by a process not yet known, or that the process has been going on eternally, but at such a rate that we cannot detect it. Since the former alternative is "against the spirit of scientific inquiry," the new cosmologists would seem forced to postulate the continual animation of matter. But their own cosmological scheme rules this out. The matter of which the earth is composed is supposed to have been created as separate atoms, and therefore could not have begun to live for many millions of years. Hence terrestrial life, if it is admitted to exist, must have begun at some particular epoch. There seems to be no escape from the difficulty except by denying the existence of living matter or by violating "the spirit of scientific inquiry." I fear that the excessive inbreeding, which is the curse of mathematical physics, is responsible for the oversight of this problem.

But if inability to see science as a whole blinds the authors to the difficulties in their scheme, I think it is lack of historical perspective that allows it to be invested with the false charm by which they are fascinated. In every age there is a certain climate of opinion that predisposes thinkers toward a certain type of view and makes it very difficult for them to resist arguments that conform to it. This could be illustrated by examples from any period in history. I will merely mention the philosophy, of which I myself am old enough to remember the later stages, which sought to explain everything in terms of matter and energy; Haeckel's *Riddle of the Universe* was a typical representative of this view. There was a fundamental basis of *substance*: this was neither creatable nor destructible, so all phenomena must be caused by its change from one form to another. Life, therefore, was simply one of the forms assumed by this substance, which in another form was kinetic energy and in another, electromagnetic strain. Hence freedom of the will was an illusion, all actions of living creatures, even the highest, being as rigidly determined as the motions of the planets.

Today this way of thinking makes little appeal; our prejudices are different. Now it is the exceptional that is out of favor. By a sort of cosmic democracy we are predisposed to deny any unique characteristic to anything, and whatever we happen to see now, all the universe must see at all times. To think otherwise is to be pre-Copernican. And just as universal determinism could point to the triumphs of Newtonian mechanics as demanding its dogmas, so this new view can point to general relativity, with its equivalence of status for all coordinate systems.

In these circumstances the voice of science is now as it has always been: "Never mind what seems the proper thing to believe; what is the *evidence* for what you say?" And the answer which the new cosmologists must give is just that which was available to the universal determinists, namely, "None at all." When you ask for the evidence that the movements of living creatures are determined, the first thing to decide is, what is a living creature? And the only answer we can give is that it is a piece of matter whose movements are not determined. Subject a mouse to given forces and calculate how it will move. If it moves that way, it is dead; if it does not, it is alive. That is the only way we know of distinguishing between the two cases. Examined scientifically, therefore, the 19th century argument ran thus: the movements of some bodies are determined, the evidence being that we have determined them; therefore the movements of other bodies are determined, although the evidence shows that they are not.

The cosmological presumption is in similar case. The great consequences that have followed our full recognition of the equivalence of coordinate systems predispose us to assert the equivalence of events at all places and times in the universe, but the evidence, such as it is, is all against it. Every process we know, on the small or the large scale, is a one-way process, showing a preference for one direction over the opposite. The system of nebulae expands and does not contract, gravitation is an attraction and not a repulsion, the entropy of a closed system increases and does not decrease, every chemical process tends toward a state of equilibrium from which the substances concerned do not of themselves depart, organic evolution proceeds in one direction and not the opposite; and so on. There is nothing whatever in nature that indicates that any course of events is reversible. Admittedly the evidence is small compared with the magnitude of the problem, but it is all we have. I accept the spirit of the cosmological presumption to this extent, that I do not believe that the universe conforms to the prejudices of the 20th century rather than to those of the 19th century. We shall be better employed in following the scientific program than in listening to either.

I hope that I need not say that none of the considerations I have put before you should tend in the smallest degree to diminish the importance that belongs to imagination in science, when the word is used in its true sense as referring to the ability to form vivid images of possible happenings, and not in the sense in which I have had sometimes to use it, as indicating the invention of arbitrary postulates. No great scientific work has been done without the free and bold exercise of this indispensable quality, and science will stop if ever it is treated as a branch of logic as surely as if it is given over to uncontrolled fancy. By all means keep imagination free, but let it be directed, and let its products be examined and properly assessed before they are announced as discoveries of the order of nature. Even idle speculation may not be quite valueless if it is recognized for what it is. If the new cosmologists would observe this proviso, calling a spade a spade and not a perfect agricultural principle, one's only cause for regret would be that such great talents were spent for so little profit. That would indeed be a sufficient calamity, but I am not without hope for the future. I am not yet convinced that facility in performing mathematical operations must inevitably deprive its possessor of the power of elementary reasoning, though I admit that the evidence against me is strong. But I have a suggestion to offer. Let our younger cosmologists forget cosmology for a space of 3 years—the universe is patient, it can wait—and instead read the history of science. I do not mean books about the history of science, though they are infinitely better than nothing, but the works of the great scientists themselves; let them read Gilbert, Galileo, Harvey, Newton, Boyle, Black, Lavoisier, Faraday, Darwin, Huxley, Pasteur, Kirchhoff, Rutherford. Then let them spend 6 months thinking over what they have read and asking themselves what meaning it has for the work of today. And after that let them return to cosmology and give their attention again to the great problems into which they have prematurely rushed. I am convinced that if they would have the courage and the greatness of mind to do this, astronomy would not only be enormously the richer, but they themselves would thank me sincerely for the advice.

I know it is difficult. I can conceive vividly enough that when one's mathematical facility greatly exceeds his judgment of scientific authenticity, the temptation to exercise it indiscriminately on any premises that will give it scope must be overwhelming; and I am too sensible of my own good fortune in being free from that temptation to enjoy the task of arraigning its victims. But it is a task which I cannot escape. One who, however unworthy, accepts the honor of presiding over one of the foremost scientific societies of the world, accepts at the same time a responsibility. The ideas to which we give publicity do not remain our private possession; they are accepted as genuine scientific pronouncements, and as such influence the thinking of philosophers, theologians, and all who realize that in no intellectual problem, however fundamental, can scientific research now be ignored. And so, when it happens that we have published, in the name of science, so-called "principles" that, in origin and character, are identical with the "principles" that all celestial movements are circular and all celestial bodies immutable, it becomes my duty to point out that this is precisely the kind of cerebration that science was created to displace. And the responsibility is not only mine; it rests on all of us. In cosmology we are again, like the philosophers of the Middle Ages, facing a world almost entirely unknown. We need to cultivate the restraint of Galileo, who left the world of angels and spirits until the time should come when it could be explored, and contented himself with such principles as he could extract with confidence from experience, though the resolution committed him to such trivialities as the timing of balls rolling down grooves. It is that self-control—the voluntary restriction to the task of extending knowledge outward from the observed to the unobserved instead of imposing imagined universal principles inward on the world of observation—that is the essential hallmark of the man of science, distinguishing him most fundamentally from the nonscientific philosopher. It is the duty of all of us, now that the old temptation is with us again, to see to it that we preserve the spirit of true scientific inquiry which, as a scientific society, we are pledged to honor.

References and Notes

* Presidential address in 1953 before the Royal Astronomical Society (London); reprinted by permission from the *Monthly Notices of the Royal Astronomical Society* **113**, 393 (1953).

1. *Monthly Notices Roy. Astron. Soc.* **108**, 372 (1948).
2. Galileo, *Dialogues on the Two Chief Systems of the World, Fourth Day* (Salusbury's translation), p. 407.
3. I. Newton, *Opera* (Horsley's ed.), iv, p. 437.
4. ———, *Opticks*, ed. 4, p. 377.
5. *Monthly Notices Roy. Astron. Soc.* **108**, 104 (1948).
6. *Ibid.*, **108**, 252 (1948).
7. This is accepted so implicitly by psychologists that it is difficult to find an actual statement of it. R. W. Russell, however, has kindly drawn my attention to the following two passages; "The term *repetition*, as applied to an event of nature, is clearly ideal and nonrealizable in any concrete case, like the term *equality* and the term *circle*. No two concrete objects in nature ever ideally equal in every respect. No two experiments on any event of nature were ever ideal repetitions, because nature never repeats herself. [G. Humphrey, *Thinking* (Methuen, 1951), p. 113.] This quite general statement is then shown to have practical importance in particular psychological experiments. The second passage is as follows: "These two constant errors, practice effects and fatigue effects, *are potentially constant errors in almost all psychological experiments, hence, become factors which must be considered in the design of all experiments.*" [B. J. Underwood, *Experimental Psychology* (Appleton-Century-Crofts, 1949), p. 29.] The terms *practice effects* and *fatigue effects* are self-explanatory; *constant* error has a technical meaning.
8. H. Bondi, *Cosmology* (Cambridge Univ. Press, 1952), p. 11.
9. In other connections the distinction between these alternatives is important, but not here. The essential requirement in this address is to distinguish between that uncontrollable something which we investigate, whatever it may be called, and the mental machinery of investigation, which we can choose freely.
10. E. A. Milne, *Modern Cosmology and the Christian Idea of God* (Oxford Univ. Press, 1952).
11. A. S. Eddington, *Relativity Theory of Protons and Electrons* (1936), sec. 16.95: E. A. Milne, *op. cit.*, p. 33.
12. A. S. Eddington, *The Philosophy of Physical Science* (1939), chap. VIII.
13. Eddington chose, among other things, certain "forms of thought," which in fact are not necessary but have usually been assumed in empirical science (*12*).
14. See, for example, E. A. Milne, *Relativity, Gravitation and World Structure* (Oxford Univ. Press, 1935) and numerous other writings.
15. ———, *Ibid.*, p. 16: "Relativity and solipsism are incompatibles. Relativity is the complete denial of the solipsist position." This is said of "relativity" and "kinematical relativity," as the context makes clear. Actually, of course, relativity has nothing whatever to do with solipsism; if there is only a single observer he can choose his coordinate system as he wishes, and if there are 10^{79} of them, they can do no more. But the passage indicates clearly enough how the purely conceptual coordinate system of relativity had become transformed into a sentient being.
16. *Nature*, **155**, 512 (1945), and, by implication, H. Bondi, *Cosmology* (Cambridge Univ. Press, 1952), p. 123.

If you have had your attention directed to the novelties in thought in your own lifetime, you will have observed that almost all really new ideas have a certain aspect of foolishness when they are first produced, and almost any idea which jogs you out of your current abstractions may be better than nothing.—A. N. WHITEHEAD.