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A Late Awakening to Gödel in Physics

When one awakens late in the morning, one usually does not fall asleep again or begin to slumber. The opposite appears to have been the case with a very late awakening to the significance for physics of Gödel's theorem about the incompleteness of mathematics. Yet, the awakening could have been very momentous in more than one respect. First, there was the eminence of Professor Hawking, who draws large audiences whenever he speaks in a public forum. Again a speech which has for its title "Gödel and the end of physics" should have seemed very provocative. There was also the prominent venue of the speech, the centenary celebration of Dirac's birthday, held in the Centre of Mathematical Sciences at Cambridge University on July 23, 2002.

All this should have set the world of physicists abuzz, but it did not, although the text of Hawking's paper could be downloaded via Internet.[1] The lack of reaction by physicists can in part be explained because most of them work on particular problems. These can be resolved with no reference to theories that claim to be all-encompassing final theories or at least great steps toward that goal. But if most physicists are indifferent, science reporters, or at least some of them, often notice what is newsworthy, and certainly if they find that the world of at least the leading physicists is astir with most unexpected news.

But no indication of this can be found in an article which appeared in the April 5, 2003, issue of *The New Scientist,* a monthly about the latest in science. Surely, if anything notable had appeared during the previous seven months about Hawking's speech, it would have been mentioned in that monthly which referred on its cover to that article with the double caption: THE MIND OF GOD and HAWKING'S EPIPHANY. It would have been more appropriate to use the caption: HAWKING'S LATE AWAKENING, or WHY DID HAWKING SLUMBER FOR SO LONG? or HAWKING AWAKE AT LONG LAST! Or to use instead of "epiphany," a word with a very positive connotation, the sobering phrase: IT FINALLY DAWNED ON HAWKING.

For surely there was a need for some sobering up. The article in *The New Scientist*, that had M. Brooks for its author and "The Impossible Puzzle" for its real title, began with a grave reminder: Fifteen years earlier Hawking claimed in his *A Brief History of Time* that it was possible to work out a final theory of physics, which then would enable us to know "God's mind." Brooks did not ask the question of whether Hawking really needed fifteen years to realize that such an expectation was illusory. Even multiples of fifteen years are not enough to straighten out a mind which has such a trivial notion of God as to yield to the hubris that God's mind can ever be read by a mere mortal. But long before the beginning of that period of fifteen years Hawking and other prominent physicists could have realized that one did not had to be a specialist on the physics of black holes to perceive the significance of the theorem which Gödel formulated in 1930.

At any rate, Hawking traced his awakening to Gödel's theorem to his reflections on the physics of black holes. There the information, or calculable data, was found to be proportional to the boundary of a black hole which vanishes when the black hole shrinks to a point where the density of matter is infinite. But, as will be argued in this paper, the physicist does not have to consider black holes or any of the latest theories of physics in order to realize that no physical theory, however encompassing, can be final.

Physicists, in pursuit of such a theory, should have found a stern warning from the moment when Gödel read a paper before the Mathematical Society of Vienna on November 24, 1930. The paper should have appeared significant by its very title,

"Ueber formal unentscheidbare Sätze der *Principia Mathematica* und verwandter Systeme I" or "Formally undecidable propositions of

Principia Mathematica and related Systems I." For the title suggested nothing less than a grave shortcoming in the famous three-volume axiomatization of mathematics which Whitehead and Russell published in 1910-1913. But by November 24 Gödel's paper had been for a week with the editors of *Monatshefte für Mathematik und Physik*, who quickly published it in its next issue, Volume 38, 1931, pp. 173-198. Being a monthly about mathematics and physics, and carrying as many article on physics as on mathematics, the *Monathshefte* was read equally by physicists and mathematicians.

The paper could not be easy reading for most physicists, or even for most mathematicians for that matter. But the gist of the paper soon began to be talked about at least among some leading mathematicians. In terms of Gödel's paper, it was not possible to come up with an axiomatization of mathematics that would have its proof of consistency within itself. Therefore any theory of physics, which contained more than a trivial form of mathematics, was subject to the restriction of Gödel's theorem. Long before black holes emerged on the horizon of physicists, physics had been heavily mathematical. In fact many physicists held a view of physics, the positivist view, that physics was the mathematical co-ordination of date of measurements.

Therefore when Hawking pointed at the positivist view of physics as the remote origin of the problem he dealt with, he in fact implied, however unwittingly, that the problem had been on hand regardless of consideration of black holes. Therefore, and again contrary to Hawking, the problem did not originate with the indeterminacy principle, which allows no precise measurements in physics and therefore no final theory. Hawking then listed the major modern efforts to unite the chief branches of physics into one ultimate theory. These are the electroweak theory, supergravity, the standard model of fundamental particles, QCD or quantum chromodynamics, the string theory, and finally the theory of everything together with its offshoot, the M theory. The conceptual ambivalence of the M theory Hawking saw as being analogous to the problem which Gödel set forth in his famous paper. In other words, Hawking had two considerations as starting points for bringing in Gödel's theorem, but from what had been said it should be clear that he needed neither of them to perceive the significance of that theorem for physics.

Regardless of what meaning is given to the word "positivist," it should not be difficult to recognize that, to quote Hawking, "a physical theory is a mathematical model." It should also be obvious that the more advanced is a physical theory the more mathematics it contains and the more advanced is the mathematics. From this the ground for connecting Gödel's theorem with physics readily follows. For insofar as Gödel's theorem states that no non-trivial system of arithmetic propositions can have its proof of consistency within itself, all systems of mathematics fall under this restriction, because all embody higher mathematics that ultimately rests on plain arithmetic. Then it follows that there can be no final physical theory which would be necessarily true at least in its mathematical part.

This should seem elementary and obvious. One may feel that one merely has to put two and two together. Did one have to wait for Hawking's paper, and for its spurious reasoning, to see that connection to be spelled out? Hawking's paper does give the impression that nobody before him spelled out that connection. But this was done clearly in 1966 and several times afterwards. The one who did this is the author of the present paper. He did so over several pages in his book *The Relevance of Physics* published in 1966 by the University of Chicago Press, which reprinted it in 1970, although it was a book of over 600 pages. Then in 1992 a new edition was brought out by the Scottish Academic Press.

After its first publication that *Relevance* was reviewed in more than a hundred different periodicals. None of the reviewers noted pp. 127-129 in the book, where I put those two and two together, so to speak. This merely shows that most reviewers do not carefully read a book to be reviewed, and some of them do not read it at all, or read only those pages that appear relevant to their own interest.

A perfect case of this was the review by Abdus Salam, who twelve years later received the Nobel Prize. He seemed to be interested only in chapter 4 which dealt with the futility of hopes to find the ultimate layer of matter or the really fundamental of fundamental particles. About the book in general Abdus Salam merely noted that its author wasted a beautiful style on what everybody knows, namely that physics is an open ended quest.

But I argue toward the end of ch. 3 that expectations about a final form of physics are illusory, a fact which physicists do not seem to know. And my argument is a setting forth of Gödel's theorem about the built-in incompleteness of mathematics. I further developed this argument in subsequent books of mine. The first of these was the text of my Gifford Lectures, given at the University of Edinburgh in 1975 and 1976, which appeared under the title *The Road of Science and the Ways to God*. The book was published by the University of Chicago Press in the USA and by Scottish Academic Press in Edinburgh. Again I discussed Gödel's theorem and physics in my book, *Cosmos and Creator* (1980). I devoted an entire chapter, "Gödel's shadow" to the same argument in a series of lectures given at Oxford in 1988. The lectures were published by Scottish Academic Press under the title, *God and the Cosmologists*. I presented this application of Gödel's theorem to physics in two other books of mine. One is my synthesis of philosophy, *Means to Message: A Treatise on Truth* (1999), the other is my intellectual autobiography, *A Mind's Matter* (2002), both books published by Eerdmans, a publisher with world-wide distribution.

My purpose here is not to settle questions of priority, let alone to vindicate the glory of a "discovery." In fact, I stumbled around 1972 on a book, published in the early 1960s, whose author used Gödel's theorem to argue against a final theory in physics. Unfortunately, I no longer remember the title of that book. Here let me resume my task of a historian of science who is specially interested in the blindness of prominent scientists to the obvious. Proofs of this interest are my monographs relating to the history of astronomy, *The Paradox of Olbers' Paradox* (1969 and 2000), *The Milky Way: An Elusive Road for Science* (1976), and *Planets and Planetarians: A History of Theories of the Origin of Planetary Systems* (1978). A further instance of that blindness is that most prominent physicists, one after another, failed to see the relevance of Gödel's theorem for physics.

All those great physicists could hardly be unaware of the impact which Gödel's paper had for mathematics. Contrary to the cliché, the impact was not that of a sudden drama. This can readily be gathered from

Logical Dilemmas: The Life and Work of Kurt Gödel by John W. Dawson Jr., a book published in 1997.[2] Still the impact was deep if one considers important statements of some of those great mathematicians. One of them, David Hilbert raised the rhetorical questions at the Second International Congress of Mathematics in Paris in 1900: "Is the axiom of the solvability of every problem a peculiar characteristic of mathematical thought alone, or is it possibly a general law inherent in the nature of the mind, that all questions which it asks must be answerable?"[3]

Obviously, Hilbert hoped that a solution was possible. At the same Congress the great French mathematician and mathematical physicist Henri Poincaré declared: "We may say today that absolute rigor has been attained."[4] Years later Hermann Weyl, one of Hilbert's collaborators, recalled the "optimistic expectations"[5] that prevailed in Hilbert's circles. Weyl also voiced in a somewhat melodramatic tone that Gödel's theorem began acting as a "constant drain on the enthusiasm" with which he pursued his work, and that this experience of his was shared "by other mathematicians who are not indifferent to what their scientific endeavors mean in the context of man's whole caring and knowing, suffering and creative existence in the world."[6]

How leading mathematicians and then the world of mathematicians reacted to Gödel's theorem is still to be investigated in detail. Well, a small segment of mathematicians were deprived of their fondest dreams and this was significant because that segment included some of the greatest mathematicians of the time. How the general world of mathematicians reacted is a story wholly neglected. And so is the story of first-rate physicists who could have but did not perceive the implications of Gödel's theorem for their fondest endeavors nor awaken to this fact whether they had met Gödel in person or not. Some of them often met him.

The first of these to mention is Einstein, who first met Gödel in 1934 in Princeton where for two years Gödel was a visiting professor. It was then that Einstein worked hard on a Unified Field Theory, which made it once more necessary for Einstein to engage the good services of a mathematician. With that Unified Field Theory, Einstein had in mind a theory even more final than his General Theory of Relativity. About the latter Einstein once quipped that even the Good Lord could not have come up with something better. In 1954 Gödel arrived permanently at the Institute for Advanced Study in Princeton where he was a colleague of Einstein. The two often walked together to and from the Institute and Einstein was most eager during those walks to talk with Gödel "philosophy, physics and politics." This is what Einstein said to Ernst Straus and Carl Seelig, a biographer of Einstein.[7] Seelig also stated that Gödel held very negative views on Einstein's ultimate aim. All this is very tantalizing.

Apparently those talks did not include Gödel's theorem and physics. At any rate, Gödel's theorem is not discussed in Einstein's well known books on the philosophy of physics, such as *Essays in Science*, *Ideas and Opinions of Albert Einstein*, and *Out of My Later Years*. In his contribution to *Albert Einstein: Philosopher Scientist*, Gödel did not touch at all on Einstein's search for a final theory. Gödel himself did not make the connection between his incompleteness theorem and physics in spite of his having done around 1951 important work on cosmology. The same is true of what is reported by Dawson about Gödel's own work in cosmology.[8]

Or take Schrödinger, who as a Viennese could hardly remain ignorant of Gödel's theorem. Had Schrödinger reflected on it, he would not perhaps have ever qualified quantum theory as "the Lord's quantum mechanics." One may also take Eddington, whose posthumous *Fundamental Theory* (1947) was an epitome of the hope that it was indeed final in the fundamental sense, which is mathematical and implies a mathematical necessity. Either there or elsewhere Eddington did not seem to know of Gödel's theorem.

In England the awakening to Gödel's theorem did not come until Turing claimed that the idea of artificial intelligence is not contrary to Gödel's theorem. The resulting debates necessitated the publication of a specially careful English translation of Gödel's paper by R. Meltzer, which appeared with an introduction by R. B. Braithwaite in 1962. There Braithwaite put concisely the importance of Gödel's paper for mathematics by recalling that the theory of ordinary whole numbers is "the piece of mathematics which is oldest in the history of civilization and which is of such practical importance that we make all our children learn a great deal of it at an early age." Braithwaite went on: "Gödel was the first to prove any unprovability theorem for arithmetic, and his way of proof was subtler and deeper than the metamathematical methods previously employed. Either of these facts would have ranked this paper high in the development of metamathematics. But it was the fact that it was a proposition of wholenumber arithmetic which he showed to be undecidable that created such a scandal."[9] Clearly, this was very different from Hawking's laborious summary of Gödel's paper. But of physics there was not a hint in that introduction.

Nor was there, as I said, any notable reaction to what I wrote about Gödel and physics in the *Relevance*, first published in 1966. Ten years after its publication I witnessed a stunning measure of unfamiliarity with Gödel paper on the part of prominent physicists. The occasion was the Nobel Conference of Gustavus Adolphus College in October 1976, where I was one of a six-member panel. The other five were Fred Hoyle, Victor Weisskopf, Steven Weinberg, Murray Gell-Mann, and Hilary Putnam. Gell-Mann spoke of the standard theory of fundamental particles. In his speech he assured an audience of two thousand strong that within three months, or certainly within three years, he would come up with a final theory of fundamental particles.

After the speech it was first the turn of the other panelists to comment. When my turn came I reminded Gell-Mann that even if he had formulate such a final theory he could never be sure that it was really final. He shouted back rather angrily. "Why not?" "Because of Gödel's theorem," I replied. "Whose theorem?" he asked again. I said again "Gödel's theorem." Then I had to spell out Gödel's name which Gell-Mann apparently had not heard before.

It seems that it was the first time that Weinberg, Weisskopf and Hoyle heard of Gödel's theorem. A month later I gave a paper on Olbers' paradox and cosmology at Boston University and mentioned Gödel's theorem. After my lecture somebody walked up to me and said that I merely presented what he had heard a week earlier in a lecture given by Gell-Mann at the University of Chicago. There, with a reference to Gödel's theorem Gell-Mann warned that a final theory of fundamental particles was not possible to formulate. Gell-Mann was wrong. Such a theory is possible to formulate, but when it is on hand one cannot know rigorously that it is a final theory.

Almost twenty years later Gell Mann published his book *The Quark and the Jaguar*, whose subject matter would have given him more than one opportunity to speak of Gödel, but he did not. In his book *The Final Theory*, Weinberg does not refer to Gödel. He merely states that a physicist can never be sure that he has all the experimental data at his disposal. Weisskopf was never interested in philosophical questions, and certainly not in his *The Privilege of Being a Physicist*. As to Hoyle he remained to the end the village atheist of the scientific community. For him philosophical questions did not exist.

I could mention other names as well. Roger Penrose, for instance, the author of *The Emperor's New Mind*, summarizes over three pages Gödel's theorem.[10] But he does not notice its relevance for physics, although he speculates at length about a still unknown form of quantum theory in order to claim that a final theory is possible. Then there is a book with the title *The End of Science* by John Horgan, a senior member on the staff of *Scientific American*. The book begins with the declaration that "Gödel's theorem denies us the possibility of constructing a complete, consistent description of physical reality."[11] This, is, of course, not what the theorem denies. Tellingly, the book contains no reference to that theorem when the subject of a final theory is taken up. Horgan is too flippant to see something significant as he quotes M. Feigenbaum, according to whom many physicists "like the idea of final theories, because they are religious. And they use it as a replacement for God, which they don't believe in. But they just created a substitute."[12] Well, the substitute has no better fate than the statue with a gold head, silver chest, iron legs, and clay feet, which Nebuchadnezzar once saw. This time the stone, destined to destroy the statue, was hewn by a human mind very keen on the laws of reason.

Silence about Gödel and Hawking was almost deafening in the report which appeared under the title, "One Cosmic Question, too many Answers," in the September 2, 2003, issue of the *New York Times*, In the report a dozen leading cosmologists were interviewed by Dennis Overbye about "The Theory of Everything." Not without reason, the reporter cast the theory as an answer to Einstein's wondering whether "God had any choice in creating the universe." Then the report added that it was Einstein's "fondest hope that the answer was no." As to the scientists interviewed, one of them, David Gross, director of the Kavli Institute in Santa Barbara, California, stated that he was fully Einsteinian "with respect to the ultimate goal of science." That goal is a theory which predicts unambiguously all the constants in the physical universe so that the universe appears as an entity which has to be what it is and cannot be anything else. Gross in fact insisted that the basic parameters of the physical world are not adjustable. In other words, such a theory excludes the possibility that the universe is contingent, that is, dependent for its existence on a factor external to it. Given the all-encompassing character of the universe, such a factor cannot be another universe, but only that being which is traditionally called God or the Creator. The reporter took no exception to the claim of Leonard Susskind of Stanford that neither God nor the universe makes the choice, but life. But what is that life which generates the universe by chance?

The report left unexploited the opinion of Max Tregmark, of the University of Pennsylvania, that the Theory of Everything is slowly dying. Actually it would not have even been able to be born in 1984, had its originators, John Schwartz of Caltech and Michael Green, now at Cambridge, thought of Gödel's theorem. For that theorem, as Hawking noted, puts an end to cultivating physics with an ultimate theory being its major goal. And that theory, if one may add, leaves entirely open the question of whether God created or did not, or whether God created freely or did not. Gödel's theorem surely counters any effort to raise, with an eye on a physical theory, an objection to the contingency of the universe.

Gödel himself retained something of his childhood belief in God. He felt a thorough disdain for materialistic positivism and saw his theorem as a devastating weapon against it. Surely, the idea of a God who can freely create one particular universe out of an infinitely large number of possibilities, could not be alien to Gödel's thinking. He could have therefore found an inner prompting to connect physics with his theorem. It is therefore somewhat puzzling that he did not see his theorem as a proof that one cannot turn physics into an argument against the contingency of the universe.

Herein lies the ultimate bearing of Gödel's theorem on physics. It does not mean at all the end of physics. It means only the death knell on endeavours that aim at a final theory according to which the physical world is what it is and cannot be anything else. Gödel's theorem does not mean that physicists cannot come up with a theory of everything or TOE in short. They can hit upon a theory which at the moment of its formulation would give an explanation of all known physical phenomena. But in terms of Gödel's theorem such a theory cannot be taken for something which is necessarily true. Apart from Gödel's theorem, such a theory cannot be a guarantee that in the future nothing essentially new would be discovered in the physical universe which would then demand another final theory and so on. Regress to infinity is no answer to a question that keeps generating itself with each answer.

Gödel's theorem means, among other things, that physicists who aim at reading God's mind will not succeed, because they cannot read their own minds in the first place. A physicist, Paul Davies, who writes a book with the title *The Mind of God*,[13] should be the object of pity and not the recipient of a prestigious prize for progress in religion. Gödel' theorem remains a serious assurance to all physicists that their minds will forever be challenged by ever fresh problems. With a recourse to logic they would also know what to think of efforts to derive the very specific constants of physics from non-specific considerations. Insofar as mathematics works with numbers, it will remain steeped in specifics all of which raise the question: Why such and not something else? It is that question which keeps the mind awake, or rather is raised by minds not prone to slumber.

1. Ogg orbis.
2. Wellesley, MA: A. K. Peters. Dawson is professor of mathematics in Pennsylvania State University in York. See also *Goedel Remembered: Salzburg 10-12 July 1983* by R. Gödel *et al*, ed. P. Weingartner and L. Schmetterer (Napoli: Bibliopolis, 1987).
3. Quoted in Dawson, *Logical Dilemmas*, p. 263.
4. Quoted *ibid*., p. 47.
5. H. Weyl, *Philosophy of Mathematics and Natural Science* (Princeton: Princeton University Press, 1949), p. 219.
6. *Philosophy of Mathematics and Natural Science*, p. 219.
7. *Logical Dilemmas*, p. 176.

8. See ch. IX, "Philosophy and Cosmology," pp. 173-192.
9. Kurt Gödel, *On Formally Undecidable Propositions of Principia Mathematica And Related Systems*, translated by B. Meltzer, with an Introduction by R. B. Braithwaite (Edinburgh: Oliver & Boyd, 1962), p. 4.
10. New York: Oxford University Press, 1989, pp. 105-08.
11. Reading Mass.: Helix Books, 1996, p. 6.
12. Ibid., p. 222.
13. New York: Simon and Schuster, 1992. See pp. 101-103 for Davies' account of Gödel's theorem which Davies surely does not see in its bearing on final theories in physics when he comes to discuss them (pp. 166-67). He takes that bearing for a support of the view that the human grasp of physical reality is ultimately enveloped in fuzziness. The author he quotes in support is an evangelical theologian for whom religion is basically a matter of emotions.