1

Review of

THE ROAD TO REALITY

Roger Penrose

Alfred A. Knopf
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~1000 pages of text
36 page Bibliography
Index

"Garlic and sapphires in the mud
Clot the bedded axle-tree"
-T.S. Eliot, Burnt Norton

"...human kind | Cannot bear very much reality"
-Ibid

"Swept with confused alarms of struggle and flight
Where ignorant armies clash by night"
-Matthew Arnold, Dover Beach

Dr. Roy Lisker
Middletown, CT 06457
rlisker@yahoo.com
www.fermentmagazine.org

A more accurate title might be "*Many* Roads To Reality. " Only a very hidebound physicist (a class to which Roger Penrose assuredly does not belong) or a religious fundamentalist would maintain that there is a unique road to reality.

Roger Penrose has gained international recognition for research into Cosmology, General Relativity, Geometric Combinatorics, Quantum Field Theory, Differential Geometry and related disciplines. He is passionately committed to the advancement of knowledge in these fields, with particular emphasis on the promotion and defense of his own ideas. They tend to be both profound and provocative, and a number of them reappear in this treatise.

Reading it from cover to cover confirmed my preexistent opinion that the "road to reality" constructed by the physicists of the last century is a riddle within a quagmire inside the realms of Chaos and Old Night. I refer the reader in particular to Chapter 26 on Quantum Field Theory , and much of what follows afterwards. The state of the subject is not unlike the style of Dr. Penrose's mastodonic book (*1049 pages of text, 36 pages of Bibliography, 14 page index*) . To embark on a reading of Penrose's treatise, "The Road to Reality" is to wander through a No-Man's Land of confusion, popular science, torturous prose , and(for the small subpopulation of humanity which has independently acquired a command of the basics treated in the first 16 chapters) a host of shrewd, even brilliant insights worthy of a Penrose.

One sees few signs of Penrose's distinction as a scientist in the overall quality of this book. Evidences of an indifferent attitude towards everything outside his fundamental research interests are strewn across its pages. The writing is mediocre at best. The teaching mode is vintage "blackboard": breezy, sketchy, redundant, with important and inessential observations mixed up with little attention to relevance. Demonstrations are presented in the wrong order. One finds fundamental ideas, (like 'orthogonality' or 'open set') hastily inserted as afterthoughts following after several, even

hundreds of pages of exposition in which knowledge of them is assumed. One will find that he uses Feynman diagrams for two chapters before explaining what they are.

It is clear that *The Road to Reality* was scantily edited, care being exercised neither by Penrose nor by Alfred Knopf. Foisting it on a scientifically ill-informed and educated general public is at best disingenuous , at worst dishonest. Our negative verdict on the bizarre mixture of haste, confusion and sloppiness that characterizes "The Road to Reality" is the fact that Dr. Penrose is not confused in the least with respect to his subject matter .

Any knowledgeable reader will recognize that Roger Penrose possesses one of the most lucid minds in the business . Very few people in the research community have the comprehensive vision of the whole which allows him to organize this veritable encyclopedia so well that everything falls into its logical place. It is because of his unique insights that a summer's reading through The Road to Reality has been very valuable for someone like myself who , at one time or another , in a sporadic manner, has studied most of its ingredients. This being the case, what's wrong with it? Alas...

For an audience with sufficient background to understand "The Road to Reality" its virtues are considerable and we present these first.

These include: shrewd observations worthy of a Penrose; insightful discussions of subjects that have been previously mastered by the reader; putting together the great jig-saw puzzle of the universe, his admirable grasp of the whole picture; a series of major critiques directed against the deficiencies of most of the "unifying" theories, or "theories of everything" of modern physics. Although the book is very thorough, there are some surprising omissions. One cannot do better in presenting the numerous models of hyperbolic geometry,(Beltrami, Poincare, etc.) . The manner in which M.C.Escher drawings are shown, then distorted is a very clever way to highlight the differences between them. At the

same time he doesn't discuss elliptic geometry at all, The normal procedure is to present this first because it has simple representations in ordinary 3-dimensional space.

Every once in awhile, in an off-hand manner, Penrose will drop a brilliant insight, there for anyone sharp enough to pick it up. Thus, on page 153, after a discussion of the unique role of analytic functions in modeling causation, he points out that this implies that "information" must be transmitted in discrete packages. An insight from causal determinism points towards quantum theory.

After raising the possibility that quaternions might have some use in physics, he shows, on page 201 that they have the wrong signature for relativity theory. As a result "conformality" cannot be extended to quaternions.

His treatment of the Dirac belt trick, on page 203 is crystal clear. The accompanying drawing clears up whatever confusion might remain.

Penrose clearly is a master of differential geometry. His explanation of "parallel transport" on page 274 is one of the I've come across anywhere. Likewise, his treatment of Clifford Bundles in chapter 15 is first-rate (for people who already know what they are!) One can say the same about his explanation of connections on pages 345-49.

Chapter 17 on Space-time. Insightful observations: the space time of Galileo's relativity is a fiber bundle; the space-time of Newtonian gravitation is an affine space.

Page 513, 545. Insightful discussions of experiments that highlight the interrelationship reality of the two "processes" (U and R) of our quantum universe: the Mach-Sehnder experiment and the Elitzur-Vaidman experiment

Page 592: Imaginative picture of our quantum-entangled world as a kind of Sargasso Sea, dubbed "quanglement" ! In general his treatment of the Bell's Theorems and their consequences is good, although he neither presents nor explains the full Bell Inequality.

Page 656: Illuminating treatment of Creation and Annihilation operators, the "Dirac sea model", the "vacuum state model", the "ultraviolet catastrophe" , etc. Penrose's mind is particularly lucid in portraying the state of a highly confused science!

Pages 690-712. Roger Penrose's celebrated arguments for a "low entropy" Big Bang. A series of critiques of the "unifying" theories of modern physics, those which attempt to bring together relativity, quantum theory and elementary particle theory, begin in Chapter 28. They reflect the views and expertise of a competent mathematician, one who has thought long and hard about such matters.

Page 755: Critique of inconsistencies of Inflationary theories

Page 758: Explodes circular reasoning of Anthropic Principle physics

Page 770: Exposes pitfalls in the so-called "Euclidization" technique.

Page 786: 6 viewpoints on "Quantum Ontology". Very well analyzed.

Page 861: Excellent arguments against J.A. Wheeler's quantum foam hypothesis. Points out that "quantum fluctuations" are insufficient to account for the formation of the galaxies.

Page 875: Intelligent critique of Supersymmetry

Page 889: Devastating 40 page critique of String Theory

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We now turn to the negative aspects of "The Road to Reality" In the opinion of this reviewer these outweigh its merits. These are:

(a) the fiction that the book can be understood by anyone not working in the fields of which it treats;

(b)the sub-standard writing;

(c)the incongruous way in which popular clichés about science and scientists are mixed in together with insights at the forefront of theoretical physics;

(d)the bad pedagogy in expositions of difficult mathematics.

On page xix of the Preface, Penrose makes the claim that *The Road To Reality* can be profitably read by 4 audiences. Quote: *"There are four different levels at which the book can be read.":*

***Class 1 :* People with so little aptitude for mathematics that they have "difficulty in coming to terms with fractions." Yet, despite claims to the contrary , Penrose assumes quite a lot of prerequisite knowledge, even erudition, from his readership.**

***Class 2 :* Readers willing to peruse mathematical formulae who lack the inclination to verify them. Penrose claimed that the problems presented in the footnotes will help them do this. I did not find them helpful. Many are either absurdly easy, others are forbiddingly difficult.**

***Class 3 :* Persons with a mathematics background who want to learn how to use the techniques and methods presented in the book. Unfortunately all too many of the mathematical expositions are flawed. Ideas and demonstrations are presented in the wrong order. The author has a tendency to correct himself as he goes along. Many treatments are truncated, while a confusing rhetoric contributes to obscure even the best of them.**

Consider this paragraph on page 478: *"The way I am dealing with this notational problem, in this book. is simply to give the general formalism using the combination of q_a and p_a with the usual sign conventions connecting p_s to q_s, while being non-specific about the particular interpretation that each p or q might happen to have (so the reader can sort out his/her own choices of signs!) When I am using the combination of x_a and p_a , on the other hand, then I really do mean the notation consistent with that of ß18.7 , so that $-p_1$, $-p_2$,$-p_3$ are the ordinary momentum components (equal to p1, p2 , p3 in a standard Minkowski frame) of ordinary spatial momentum. "*

A question: If p_a is printed alone apart from q_a and x_a , what convention should we use?

Class 4: **The math/physics professionals . Penrose is quite correct when he says: "... You may find that there is something to be gained from my own perspective on a number of topics..."**

Yet, why should an "expert" spend $40 on a popularizer of a subject he already knows, just to expose himself to yet another exposition of Penrose's perspective? Either he's already encountered this perspective through numerous lectures, articles and books, or he will decide to visit the science library at the local university, where he can devote a pleasant hour or two thumbing through the 400 pages between chapters 26 and 34.

It is unlikely that the combined sales in all classes, including those to libraries and research institutions, will do more than cover the cost of ink and paper. It is possible that Alfred Knopf was more interested in the prestige value of such a book, as opposed to its profitability. That prestige however is not enhanced by a product as carelessly put together as this one.

Clear writing is not only important for good exposition, but essential as well to correct thinking. It does indeed 'matter' that a the presentation of a discourse is confused. The reader may have the sense that he knows what is being said, only to find out, once he tries to use the ideas he's learned in his own life and work, the extent to which he's been short-changed. The following sentence on page 48 is something of a benchmark of the level of discourse throughout the entire book

" For Hamilton found that ij=-ji , jk = -kj , ki =-ik , which is in gross violation of the standard commutative law."

(a) What is a 'gross violation' of the commutative law. Is it worse than a 'gentle violation' of same law ?

(b) What is the 'non-standard' commutative law? Sentences like the above, though standard (sic!) in most popular science writing, suggest that not much editing was done on a manuscript that Penrose claims took him 8 years to write. In the Acknowledgments, he generously credits Eddie Mizzi and Richard Lawrence for help with editing. How could they have missed so

much? What is certain is that the staff editors at Alfred A. Knopf did virtually no editing, and a half-hearted job at proof-reading. Turn to page 841 for the worst example of the latter.

Publishers of books and magazines tend to take two possible approaches to arcane scientific texts. The first, of which Scientific American is a notorious practitioner, is to systematically rewrite every article accepted for publication in a dull-as-dust, predictable house style. Everything looks and feels as if it came from the same assembly line, and only people with a high degree of interest in a particular subject matter will take the time to read articles about it .The other is to assume that the ideas embedded in the turgid prose are so advanced and arcane, that to change even a single word would bring down the condemnation of the scientific establishment of which he is a member. This appears to have been the policy of the editors at Alfred Knopf.

Below is a small selection of the many examples of substandard writing in the book:

Page 247 ***:"Yet, remarkably, according to the highly successful physical theories of the 20th century, all physical interactions (including gravity) act in accordance with an idea which, strictly speaking, depends crucially upon certain physical structures possessing a symmetry that, at a fundamental level of description, is indeed necessarily exact!"***

Page 528 ***:" This alternation between these two completely different-looking procedures would appear to be a distinctly odd type of way for a universe to behave."***

The point, of some importance , is lost in the garble.

Page 613*:"It seems to me that this remarkable relation between an essential physical requirement, on the one hand, and an elegant mathematical property, on the other, is a wonderful instance of the deep, subtle, and indeed mysterious relationship between sophisticated mathematical ideas and the inner workings of the actual universe. "*

Page 657:*"I shall certainly not be able to go into great detail in my description of this magnificent profound difficult sometimes phenomenogically accurate yet often tantalizingly inconsistent scheme of things."*

It is not required of an expositor of current science that he be a prose master like Bertrand Russell or d'Arcy Thompson. Prose like this however is beneath any acceptable standard.

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The Road to Reality **combines an overly scrupulous concern for priority recognition with a shallow depiction of the life and work of major figures showing little respect for historical scholarship. On page 81 he reminds us that the properties of what is known variously as the "Argand diagram" or the "Gaussian plane" were first discovered by Caspar Wessel (unknown for anything else) in 1797. To learn more about Wessel I consulted Florian Cajori's "History of Mathematics" (1980. Paraphrasing pg. 295 :**

" Caspar Wessel .. employed as surveyor by the Danish Academy of Sciences .. Essay on the Analytic Representation of Direction .. published in Vol. V of the memoirs of the Danish Academy ... article buried for a century ..French translation published in1897..." The writings of Wessel and Argand being little noticed, it remained for K.F. Gauss to break down the last opposition to the imaginary."

Having thus admirably restored the reputation of a forgotten champion of science, one might assume that Dr. Penrose would behave with an equal concern for such distinguished figures as Pythagoras, Plato, Leibniz, Aristotle and others. Such is not the case.

Granted that only the most fastidious math historian would be outraged rather than amused by Roger Penrose's popular science exhumation of the life and works of Pythagoras. From page 5 of the Prologue we learn that the "sage" Pythagoras maintained a"brotherhood" of 571 wise men and 28 wise women at Croton in southern Italy.

On page 10 he gives "dates" for "Pythagoras of Samos" as 572-497 B.C.E. Yet in a footnote he admits that*" almost nothing reliable is known about Pythagoras, his life, his followers or their work."* Ignoring his own cautionary note, he then attributes to Pythagoras the discovery of the idea of mathematical proof .

The rest of page 10 is filled with a long list of accomplishments and discoveries by these anonymous figures.

Coming to Plato, the astounding scope of one of the greatest minds in history is 'captured' by a simple thumbnail catch-phrase:

Page 11: *" ..Plato made it clear that the mathematical propositions [.....] inhabited a different world distinct from the physical world. Today, we might refer to this world as the Platonic world of mathematical forms . "*

A better reading of Plato would be that mathematics *mediates between* the world of pure forms and the physical world, and therefore has a foot in both. No matter: my objections to Penrose's one-line description of Platonism are not so much concerned with his superficial version of the "story of philosophy", but to the obvious disdain that he and many research scientists manifest towards the kindred disciplines of philosophy and the history of science. Somehow it never seems worth their time and trouble to "get it right".

Despite this Penrose now devotes all of section 1.4 to a travesty of serious philosophy in his meditations on "the three deep mysteries": the connections between the physical, the mental and the Platonic mathematical . The shift from arid Platonism to penny-ante neo-Platonism has been made without missing a beat. It's threadbare "popularized philosophy" from the pen of a brilliant mathematician and major scientific figure, the long tradition from Will Durant to Bertrand Russell notwithstanding.

The low point is reached in his portrayal of "Aristotle" and "Aristotelian thought" in Chapter 17 on Space-time. On page 382 he writes:

" In Aristotelian physics, there is a notion of Euclidean 3-space E^3 to represent physical space."

Apart from the indirect evidence in this book that Penrose has never studied Aristotle's physics, one should look at the comparative dates for Aristotle and Euclid. A reliable estimate is that Aristotle's lived between 384 and 322 BCE He directed the Lyceum in Athens from 335 to 323 . Euclid's Elements were published in Alexandria, where he'd spend 10 years working on them in around 320 BCE, that is to say, 2 years after Aristotle's death.

In fact Aristotle's physical meditations have very little to do with Euclidean 3-Space, and less with any notion of a geometrized "space-time". In the whole of Aristotle's *Physics* he only mentions geometry once, in connection with the infinite divisibility of continuous arcs. Rather than geometry, Aristotle analyses Matter, Form, Void, Efficient Causes, Final Causes. His cosmology as presented in the Metaphysics is very different from anything Penrose attributes to him. Yet on page 384 of "Road to Reality" Penrose has the audacity to write:

" In this I am taking an idealized view of what might be called 'Aristotelian dynamics', or 'Aristotelian physics', and I take no viewpoint with regard to what the actual Aristotle might have believed!"

This is very strange indeed, given that Aristotle's treatises on physics have been extensively studied and hotly contested for 23 centuries! In that time hundreds, if not thousands, of commentaries have been written by Greek, Hellenistic, Roman, Jewish and Christian philosophers, theologians and scientists. There is absolutely no excuse for a major scientist (even in a popular book) to invoke a notion of "Aristotelian physics" that has nothing to do with Aristotle's physics. Imagine a popular book on physics carrying statements like : "Lets call this 'Einsteinian physics'. Oh, by the way, I've no idea what the real Einstein thought."!

Penrose's discussion of Galilean , Newtonian and Einsteinian space-time is of course more respectable, that is to say he knows what he's talking about. I would have liked him to mention the very important universe models of Descartes and Leibniz. Descartes' "horror of the vacuum" has resurfaced in our own day in Dirac's "electron sea", while Leibniz brilliant critique of Newton's absolute space and time delivered its delayed fruits in General Relativity. The message, alas, is clear: "Who needs philosophy?" Yet such disdain does not hinder him from devoting all of Chapter 34 to "philosophy" of a sort: mixing the shrewd with the trite, thumbnail explanations, superficial glosses on major questions and a penchant for inaccuracy he would never tolerate in his own mathematics.

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The most serious failings of The Road to Reality lie in its expositions of mathematics. Of the four target audiences mentioned in the Preface , the first is defined as those who find all mathematics mystifying. However many of Penrose's explanations are mystifying not only to two, but to all 3 remaining classes of readers, including the experts. Here is a particularly glaring example:

Page 642: *" A general U(2) transformation of the Hermitian matrix (which we must bear in mind involves both pre-multiplication by the U(2) matrix and post-multiplication by the inverse of that matrix)does 'churn around' the elements of this Hermitian matrix, in very specific ways, but its Hermitian character is always preserved. In fact this analogy is very close to the way in which U(1) indeed acts in electroweak theory (the only complication being that we must allow for a linear combination of the diagonal elements with the trace, in this identification, related to the 'Weinberg angle' that we shall becoming to in ß25.7) "*

Incomprehensible gobbledygook to someone who doesn't already know the subject. *What* **"analogy" ?**

Then there is the inconsistency of his notation. In this he is not alone: many serious textbooks at the graduate level suffer from the same defect. What is puzzling in "Road to Reality" is exemplified by a particular passage on page xxviii in the section on "Notation". Here he establishes a certain notational convention that will be subsequently ignored:

"Sometimes I use C as an adjective, to denote 'complexified', so that we might consider the complex Euclidean 4-space, for example, denoted by CE4....

"The adjectival role of the shell letter C should not be confused with that of the lightfaced san serif C , which stands for "complex conjugate of' (as used inß13.1,2). This is basically similar to another use of C as in particle physics, namely charge conjugation, which is the operation which interchanges each particle with its anti-particle (see Chapters 25,30)."

Turning to section ß 13.1, on page 248 we discover that he uses the "shell" C to stand for the Complex Plane, an idea very different from the "Complexified Plane", which his system notates as CE2 . Now the "Complex Plane" is actually the same thing as his "Wessel Diagram" which he discusses on pages 81 to 83 without giving it any label. The mystification is completed by his discussion of "complexification" on page 414, in which he says , essentially, that C4 and CE4 are really the same thing! Throughout the rest he is as likely to use one as the other, and once in awhile he reminds the reader that they are the same thing, as on page 417.

All this is quite minor in comparison to his masterstroke of obfuscation: the use of tensor diagrams, starting on page 241. These are tiny diagrams that must look peculiar to anyone not working as a specialist in Knot Theory, Topological Quantum Field Theory and the mathematics of "q-deformed matrices". Totally mystifying to outsiders, they reduce the readership to the tiny elite who understand them.

As if reminding himself that he must do something for the general public, on page 260 he allows that his reader may not even know what a "determinant" is! After writing up a 4-page crash course on Determinants, he then proceeds to "prove" the fundamental theorem of determinants, (DetADetB = DetAB), A and B square matrices of order n)through appeal to a particularly incomprehensible tensor diagram on Page 264! This exotic mixture of first-year college level with 3rd year post-doc specialization must be unique in the history of science popularizers.

Despite his recognition that there might be readers out there who may not know what "determinants" are , Penrose then crams a year's graduate course on Field Theory into 3 pages(449-451)!

The worst failing of the book in this domain is, to my mind, the absence of any introductory material on Topology. Given that most of the material in "Road to Reality" is about modern theoretical physics, Penrose should have dropped the chapters about the real number system and substituted one on Topology. Instead he provides hasty definitions of every topological concept as it arises: "open set", "closed set", "compact", "connected", "Hausdorff set", etc. , as if saying : "I guess I forgot to tell you, but this word means..." . Following some one word or one sentence definition, he then blithely assumes that the reader's used these notions all his life, forging ahead incomplete confidence that he's being followed.

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Summary

The Road to Reality **is really only written for persons who've already studied the subject matter of its contents. It is virtually unedited. Competent editing would have winnowed its bulk from over 1000 to about 500 pages . It is very complete; indeed it tries to do too much. It can be used as a reliable reference book at a rudimentary level for professional theoretical/mathematical physicists. For all other classes of readers it is unfortunately likely to be a disappointment.**

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