process, they introduce the makers of the neo-Darwinian synthesis and their accomplishments. New arguments surrounding group selection and sociobiology are summarized.

The last two sections of the Epilogue address the phenomena of (1) human consciousness and (2) religion and God. The penultimate section argues for an (evolutionary) emergentist origin of mind; it includes a rebuttal of some of the claims of epiphenomenalists such as Daniel Dennett, as well as a counterbalancing critique of Thomas Nagel's attack on evolution as insufficient to explain the origin of consciousness.

The final section includes an examination of the arguments of Jerry Coyne to the effect that evolution precludes theism. Prominent Christian evolutionists such as Kenneth Miller and Simon Conway Morris are acknowledged. The authors demonstrate that Coyne's logic is overextended; they identify and rebut examples of *ad hominem* attacks on religion as well as argumentation by fiat. During this discussion, Stephen Jay Gould's proposed resolution for the science-religion conflict, that of "non-overlapping magisteria" (NOMA), is introduced but rejected as too simplistic: "Coyne doesn't mention it, but from the science side, values flow across any proposed boundary; that is, science itself is grounded in values" (p. 228).

The authors invoke Friedrich Schleiermacher to describe Coyne, Richard Dawkins, and others as contemporary "cultured despisers of religion." They urge the adoption of a more intuitive sense of awe in the face of the cosmos, a sense which naturally undergirds a scientific curiosity. Ruse and Richard ably demonstrate that Darwin, while far from a devout theist, could not shake the sense that some agency lay behind the universe.

> This is not Gould's doctrine of separate magisteria, rather this view of religion is not merely compatible with science, it is necessary for the advancement of science. And, perhaps, for leading a coherent life, one in which the appreciation of poetry, art and religion provide the same kind of experience that leads creative scientists to advance beyond their more pedestrian colleagues. Darwin was one such as these. (p. 233)

Darwin gets the last word here, and that is as it should be given the logic and flow of the volume. Darwin's theology, thin as it is, will not be attractive to either contemporary atheists or robust theists; that discussion best resides in a different venue. *Debating Darwin* is well organized, insightful, and informal. It succeeds as a concise introduction to Darwin the scientist and human being, as well as to his contemporaries and successors. An enjoyable read and an edifying one, useful to many different audiences.

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Physics

FASHION, FAITH, AND FANTASY IN THE NEW PHYSICS OF THE UNIVERSE by Roger Penrose. Princeton, NJ: Princeton University Press, 2016. 520 pages. Hardcover; $29.95. ISBN: 9780691178530.

Eminent mathematical physicist Roger Penrose continues to indulge his prolific writing habit, offering us yet another popular work with an irresistible title. *Fashion, Faith, and Fantasy in the New Physics of the Universe* is his latest attempt to explain the challenges and prospects of twenty-first-century theoretical physics. The book's title appeals to a popular-level readership, and it is sure to end up on the shelves of many aspiring and ambitious readers. However, this is not light reading, and even those with an extensive physics background will find this volume a challenging read. Even so, there are valuable perspectives given by Penrose that only someone of his stature in the physics community can offer, and that should be taken seriously.

The book is divided into four lengthy chapters, each about 100 pages of a nearly self-contained treatise on a subject. The first chapter, Fashion, is about the development of string theory, the most fashionable theory amongst practicing theoretical physicists with its promise of providing a mathematical scheme of unifying all four fundamental forces of nature. Criticisms of string theory have focused on its grand claims of numerous unseen dimensions and a possible glut of unseen universes, while offering virtually no firm testable predictions. However, Penrose is a gracious critic, and points out many intriguing ideas that have come out of string theory, including some surprising advances in mathematics. Indeed, mathematical elegance has served as the guiding principle, in lieu of experimental data.

Penrose guides the reader through the theoretical challenges that motivated string theory in the first place: a desire to find a unique unifying scheme that brings quantum field theory (QFT) into consistency with universal gravity, which already has a very successful classical treatment in Einstein's general relativity. The common wisdom is that gravity must be properly quantized to be compatible with QFT. Faced with perplexing divergences that arise in normal

QFT when particles are treated as objects occupying singular points in space, string theory finds a clever way to avoid those, if all particles really are tiny 1-D strings vibrating in higher dimensional space. Further coupled with supersymmetry, which proposes a correspondence between half-integer spin particles called "fermions" and integer spin particles called "bosons," string theory proposes to solve several theoretical problems. However, supersymmetric particles have not yet been observed. In addition, the mathematical consistency is not clear—a troubling issue that Penrose believes has been ignored in the excitement over string theory. He argues that the excessive functional freedom from the higher dimensions has not been properly addressed. Singularity theorems from Penrose and Hawking in general relativity appear to imply instability of the highly curved extra dimensions posited by string theory.

Disturbingly, rather than finding a unique unifying scheme, theorists found that there were several different viable types of string theories. Connections found between them led to M-theory, suggesting vibrating "branes" of more than 1-D. Intriguingly, ideas such as AdS/CFT correspondence led to applications in diverse areas of physics, ranging from condensed matter to black holes to cosmology. Yet the most perplexing turn in string theory came when it was found that different starting vacuum states lead to completely different universes, as many as 10^{500}, and thus a "landscape" of universes. Are these "real" or merely mathematical? The conclusion reached by some physicists is that, out of the multitude of existing universes, we just happen to occupy an improbable one that is life friendly—a rather sad version of the anthropic principle. Penrose poignantly points out the irony in this sorry state of string theory. Must string theory really throw away the goal of finding a unique description of nature and conclude that there is no such unique description? This is a strange departure from its initial motivation, and Penrose finds this unacceptable.

In chapter 2, "Faith, an Overview of Quantum Theory," Penrose begins to point out where he believes the problem lies. The overwhelming success of quantum theory in modeling the behavior of matter is unquestioned. This is precisely the point that Penrose believes should be reviewed. Quantum theory leads to some rather troubling views of reality, including the apparent nonlocality of how entangled states behave. Entangled states imply that a particle is simultaneously in more than one state and connected in an overall state to another particle, such that a measurement made on one immediately forces the other into a certain state, no matter how far apart they are separated. The EPR effect, named after Einstein, Podolsky, and Rosen, has now been observed in the entanglement of particles separated by up to 143 km. This cannot be reconciled with any kind of classical explanation, and thus represents a further triumph in the utility of quantum theory. However, the concept of entanglement leads to some very troubling implications including not only the eerie aspect of nonlocality, but also what is considered "real" or merely a convenient calculational tool.

The Copenhagen interpretation of quantum mechanics does not assign any kind of ontological reality to the wave function of a particle, treating it only as a calculational tool for giving us probabilities, which are in spectacular agreement with "real" measurements. Accordingly, there is no real sudden "jump" from a calculated quantum state to a measured state. It is merely viewed as a shift in our knowledge of the state. However, Penrose questions this view, pointing out that a reality can and should be argued for the quantum state itself. Penrose argues that the connection between quantum states and measured states lies in a better understanding of the reduction measurement itself. The resolution Penrose offers is that gravity limits the extent of quantum superposition. A gravitational self-energy arises when considering two different locations for a massive particle. Penrose explains how this forces instability in any quantum superposition, collapsing it into one state. Thus, rather than forcing general relativity to conform to an unquestioned quantum theory, it is quantum theory that should be treated in a more limited sense. Experimental tests on the limits of entanglement may soon extend to larger mass displacements, allowing an important test on the limits of our quantum "faith."

Chapter 3, Fantasy, describes modern cosmology. The standard Big Bang model has achieved remarkable success in accurately describing an expanding universe filled with ordinary matter, dark matter, and dark energy. Success in predicting the cosmic microwave background radiation (CMBR), discovered in 1965, and its tiny fluctuations in temperature, discovered first in 1992 and more recently refined in its precision, is nothing short of fantastical. Penrose describes the theoretical developments of the Friedmann-Lemaître-Robertson-Walker (FLRW) model of cosmology, founded on Einstein's general relativity. The successes of inflationary theory in explaining special features of our universe are discussed. However, the FLRW cosmological model represents a unique condition of homogeneity and isotropy that present theoretical physics ideas do not explain.

The Second Law of Thermodynamics implies that the entropy of the universe is much greater today than in its infancy, when it exhibited an exquisite order. The apparent contradiction of the thermodynamically smooth CMBR temperature, a highly entropic state achieved long before the moment of decoupling at 380,000 years after the big bang, is reconciled with the Second Law by comparing it to the exceedingly vaster entropy of today's universe, filled with black holes. The problem is not the Second Law, but rather the explanation of why the universe exhibited such extreme order in its infancy, with no degrees of gravitational freedom perturbed. Appeals to the anthropic principle, that this universe was simply selected out of a large landscape of universes, strike Penrose as rather unconvincing. Penrose responds:

> It is, to my mind, disturbing how frequently theoretical physicists eventually come to rely on such arguments in order to compensate for a lack of predictive power that their various theories turn out to have. (p. 322)

Penrose is critical of theorists, not for offering fantastical ideas to explain the special features of our universe, but because, at present, they are not fantastical enough. New ideas are needed.

Penrose concludes his book with a chapter on his own favored theoretical approach, "twistor" theory, an approach he first proposed in 1967. Twistor theory attempts to unite quantum theory with a relativistic space-time physics in an abstract twistor space that renders space-time itself a secondary notion. The power of complex analysis is utilized in the twistor space computations. The theory is definitely the domain of mathematical physics. However, in contrast to string theory, it does not propose any space-time dimensions beyond our observed four dimensions.

The mysterious quantum features that Penrose claims can be explained with twistor theory include nonlocality and quantum state reduction. Nonlocality arises naturally in the formalism of twistor theory. It explains all quantum state reductions as gravitational effects, forcing superpositions of states to decay into measurably "real" states. Penrose calls the latter "objective reduction" (OR). The premise of Penrose is that quantum theory must be limited in its domain. However, problems in using twistor theory include aspects of cohomology and the "googly" problem, areas in which Penrose believes progress is being made. As for problems in cosmology, Penrose proposes a conformally cyclic version with pre-big-bang world-lines connecting to post-big-bang world-lines, so that a Weyl curvature hypothesis can be employed. The latter is an attempt to explain the special FLRW condition of standard big bang cosmology, even without a period of inflation.

Penrose's book takes the reader on an extensive journey that summarizes much of Penrose's life work. Unless the reader has extensive prior knowledge of mathematical physics, it will be difficult to grasp many of the technical points made. Penrose provides a 70-page mathematical appendix to help nontechnical readers, but it appears to be of very limited utility unless one already has familiarity. It might have been better for Penrose to attempt a much more lay-reader-friendly book, focusing primarily on the key aspects in which modern physics has struggled, but thus far has fallen short of satisfactory answers. Indeed, hidden between technical sections are excellent discussions that provide a compelling case that we have not yet arrived at satisfying answers to many of the deepest questions raised in modern physics. As for making a good case for the viability of twistor theory, this reader remains unconvinced. I am much more persuaded that he loves conformal mathematics.

Finally, what kind of connection can a Christian find between the frontiers of theoretical physics and faith? Penrose is restricted to faith in the unquestioned truth of quantum theory, not compared favorably to a religious faith, which Penrose relegates to mostly unchanged messages dating back thousands of years. Is our Christian faith a stagnant one, unchanged by time or advances in science? Granted, the central message of Christianity, the substitutionary atonement offered to believers by the life, death, and resurrection of Christ, will not be altered by advances in science. However, modern science continues to raise important questions not readily answered in scientific terms. As argued by Penrose, appeals to an anthropic principle as an explanatory tool simply reveal the lack of a fully satisfactory explanation. What modern physics has revealed includes the elegance, the order, the symmetries, and the precision we observe in this universe, all of which are highly compatible with the Christian faith in a Creator of unfathomable wisdom.

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