AUTUMN BOOKS

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COSMOLOGY

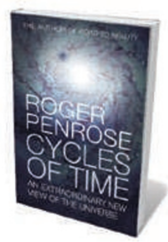
Space–time turn around

Lee Smolin marvels at Roger Penrose's masterly and imaginative argument that our Universe is one of a succession.

No living physicist has yet made a discovery as great as those of Isaac Newton or Albert Einstein, but Roger Penrose is in a better position to do so than most. Combining a mastery of mathematics with trust in his own research compass, Penrose — a mathematical physicist at the University of Oxford, UK — is driven by a heroic obsession to understand fundamental puzzles about nature. The depth of his thinking and fertility of his creativity concerning the mathematical foundations of modern physics place him above his peers.

In *Cycles of Time*, Penrose introduces his most outrageous and subtle idea yet. Answering the question of why the future is so different from the past — why eggs crack into pieces that never spontaneously reassemble, for example — he lays out his thinking on the origin and fate of the Universe. Penrose addressed this problem in his first popular-science book, *The Emperor's New Mind* (Oxford University Press, 1989). His latest volume describes a new way of resolving that problem. It is an astounding idea, which, if true, would revolutionize physics and cosmology.

We should pay attention because Penrose has repeatedly been far ahead of his time. The most influential person to develop the general theory of relativity since Einstein, Penrose established the generalized behaviour of space-time geometry, pushing that theory beyond special cases. Our current understanding of black holes, singularities and gravitational radiation is built with his tools.



Cycles of Time: An Extraordinary New View of the Universe
ROGER PENROSE
Bodley Head: 2010. 320 pp. £25

His work in the 1960s on quantum gravity has borne dramatic fruit within the past five years. Penrose introduced two influential concepts: spin networks, which in 1988 seeded an approach called loop quantum gravity; and twistor theory, a recasting of space-time geometry that has generated a recent breakthrough in our understanding of gauge theories, the basic ingredients of the standard model of particle physics.

Readers will not be disappointed with the audacious ideas in his latest book. It starts with a masterful explanation of the directionality of time. A gifted popularizer of science, Penrose skilfully breaks the normal rules by including equations and describing subtleties and uncertainties. He is honest too, clearly distinguishing established science from his own speculations, and relating opposing views and alternative ideas with balance.

Penrose then sets out his proposal. It rests on the puzzle that the apparent initial state of the Universe is highly improbable — a quandary he has emphasized for years. By running the laws of physics backwards from the Universe's present state, we can work out what it looked like just after its birth. But given all of the possibilities conjured up by physics, it is extremely unlikely that a randomly picked universe will resemble our own.

The initial state of our Universe is special, Penrose argues, because it is simultaneously very hot and very cold. The matter and electromagnetic radiation are exceedingly hot, at a temperature that approaches infinity as we go back in time to the singularity of the Big Bang. But because there is no energy in gravitational waves, he says, the geometry of space-time has a temperature of essentially zero. Both extremes mean that we can simplify our description of the state of the Universe.

COOL GEOMETRY

At extremely high temperatures, the elementary particles that comprise matter and radiation are indistinguishable and their interactions negligible because their energies are tiny compared with the Universe's heat. The newborn Universe is essentially a hot gas of photons, and everything that happens to that gas is determined by one number: its temperature. The coldness of the space-time geometry also means that we can simplify its structure — at zero temperature there are no black holes and space is uniform.

Penrose argues that the direction of time is explained by the evolution of the Universe from this special, simple and improbable state to more probable ones. The unfolding of increasing numbers of random events drives the arrow of time. This is an expression of the familiar second law of thermodynamics that randomness — or entropy — tends to increase. The problem of explaining the arrow of time is then reduced to the question of why the early Universe was so special.

Penrose tries to answer this by turning from the very early Universe to its extreme future. As it expands, the density of matter — and hence energy from ordinary stuff — wanes. But the 'dark energy' associated with the vacuum of space remains constant (at least in simple models of it) and eventually dominates. Dark energy accelerates the expansion, further diluting the matter. All black holes will evaporate and any other space-time features will be ironed flat by the exponential expansion. Stars and galaxies will dissemble if, as Penrose postulates, elementary particles eventually decay to photons and other massless particles.

If these hypotheses are true, then at very late times the Universe will look a lot like it did at very early times — its spatial geometry is homogeneous and flat, and it is filled with a gas of photons. There is one difference: the temperature and density of the early Universe differ by an enormous factor from its end point. This can be understood as a change of scale, such that an act of compression — by a vast factor — could turn the late Universe into the early one.

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Penrose pulls one more trick out of his hat: the insight that physics in both the early and late regimes is insensitive to scale. Briefly, this is because massless particles move at the speed of light, at which point time stands still for them. Because there is no clock ticking, there is no reference against which they can measure a scale of length or time.

So if the only difference between the very early and late Universe is scale, and physics in both of these extremes is insensitive to changes of scale, then it is possible that our early Universe is the late Universe of a previous era. This is Penrose's big idea: deliciously absurd, but just possibly true. Moreover, it doesn't matter if such a transition took an eternity — photons are insensitive to the passage of time.

Penrose's concept joins several other proposals, such as loop quantum cosmology, that replace the Big Bang singularity and allow time to run before the Big Bang occurred, suggesting our Universe is the progeny of a previous one. Other ingenious mechanisms for making the history of the Universe cyclic — so that it repeatedly swells and contracts — have been proposed by physicists Paul Steinhardt and Neil Turok and their colleagues. But these exotic proposals involve theories of quantum gravity, which Penrose has no need for in his hypothesis.

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INFLATION POPPED

Penrose's proposal has another advantage, in common with other hypotheses that eliminate the singularity. It suggests that before the Big Bang, there would have been plenty of time to set up the correlations seen in observations of the cosmic microwave background and distributions of galaxies. Consequently, there is no need for the hypothesis of rapid inflation of the Universe very early in its history. This is potentially a good thing, because inflation is hard to stop once it is started, and can easily lead to a multiverse with an infinite number of universes like our own.

The multiverse scenario raises challenges because the explanation for why our Universe is like it is must then rely on untestable assumptions about an infinite ensemble of unobservable universes. This in turn raises puzzles about applications of probability, and requires use of the anthropic principle — further decreasing the empirical content of the theory. The anthropic principle posits that our Universe is one among a vast ensemble, most of which cannot contain life. Because one is free to make arbitrary hypotheses about the other universes, which are neither observable nor need be like our own, almost any property of our Universe can be explained away. All of these problems are avoided by hypotheses such as Penrose's that invoke a succession of universes rather than an unobservable infinite simultaneous plurality.

Despite this, inflation has so far proved successful in accounting for the observed patterns in the cosmic microwave background. The challenge of scenarios of succession such as Penrose's is to account for those observations and make a prediction that differentiates it from inflation. Then experiment can decide. Penrose's proposal therefore needs development and reflection as a scientific idea.

Cycles of Time starts off as a masterpiece of pedagogy and becomes more challenging as the book progresses. But it is worth reading to see Penrose's extraordinary mind working to confront one of the fundamental puzzles of our present understanding of the Universe. ■

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