SPACE, TIME, AND CAUSALITY

by John Polkinghorne

Abstract. The characters of space, time, and causality are issues that are constrained by physics but that require also acts of metaphysical decision. Relativity theory is consistent both with the idea of an atemporal block universe and with a temporal universe of true becoming. Science's account of causal properties is patchy and does not imply the closure of the universe to other forms of causal influence. Intrinsic unpredictabilities offer opportunities for metaphysical conjecture concerning the form that such additional causal principles might take. Different theological understandings of how God relates to time afford legitimate criteria for differing metaphysical decisions about the nature of temporality.

Keywords: active information; block universe; causality; classical theology; Albert Einstein; metaphysics; open theology; relativity theory; space; temporal universe; time; unpredictability.

Understanding of the three categories of the title is certainly influenced by science's exploration of the physical world, but the characters of space, time, and causality are matters that also call for metaphysical decision. Physics constrains metaphysics but does not determine it, rather as the foundations of a house constrain the edifice that can be erected upon them but do not fix its detailed form.

Albert Einstein lived close to the frontier between physics and metaphysics. Creative research in science depends upon both the empirical nudge of nature conveyed through new experimental findings and the conceptually creative leap of the human imagination in analyzing phenomena. For Einstein, it was the latter that played the dominant role. His discovery of special relativity seems to have owed little to the failure of the Michelson-Morley experiment to detect an aether drift and much to his

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imaginative engagement with what it would be like to travel on a light wave, together with his ruminations about how the synchronization of clocks required that light signals should have a velocity that is a universal constant of nature, independent of the state of motion of the source that emits them. Einstein's greatest discovery, general relativity, stemmed from the realization that one would be unaware of gravity in a freely falling elevator. The principle of equivalence (the numerical equality actually observed between gravitational mass and inertial mass, despite the logical distinction between their definitions) enabled Einstein to recognize that all bodies follow the same trajectory in a gravitational field, a universality that allowed him to convert gravitational physics into the geometry of spacetime.

Einstein also had metaphysical convictions of a more general kind. He believed passionately in the reality of a physical world open to our investigation. This is a common article of faith among scientists, but in affirming it Einstein confused realism with objectivity, insisting that the physical world should be clear and determinate in its character. This belief led him to reject the probabilistic understanding of quantum theory as it developed in the mid-1920s. With his 1905 interpretation of the photoelectric effect Einstein had been one of the grandfathers of quantum physics, but as it grew to maturity he came to detest his grandchild. He was a truly great physicist, but his place in the canon is as the last of the ancients rather than as the first of the moderns.

SPACE

Space may seem to be the least problematic of our categories, but that is probably because our ability to move around in it makes it seem familiar. Special relativity tied space and time together in a single package deal. In actual fact, the existence of reliable measuring rods capable of quantifying distance is scarcely less remarkable than the existence of synchronizable clocks.

The Newtonian concept of space as the container in which isolated atoms are free to rattle around and impinge upon each other has been replaced in modern physics by the altogether more integrated and relational picture of the interconnection between spacetime and matter that is offered by general relativity. Matter curves spacetime, and the curvature of spacetime bends the paths of matter. There are singular points in space, lurking at the centers of black holes and primordially present in the initial singularity of the Big Bang. Perhaps these singularities are the entries into "wormholes" that link our universe to other worlds, as some speculate. Combining general relativity with quantum theory is a project still not totally consistently fulfilled, but qualitative considerations lead one to expect that space "dissolves," becoming foamlike or granular, at very short distances of the order of 10^{-33} cm. Space is certainly likely to be more peculiar than we customarily think, but neither physicists nor metaphysicians seem to devote much effort at present to wrestling with spatial issues.

TIME

The nature of time is much more widely recognized as posing some perplexing questions. A favorite quotation of writers on the subject is Saint Augustine's acknowledgment in the *Confessions* that he knew what time was until he came to think about it, but at that point his confusion began.

A much agitated issue is whether time actually flows or whether the strong human impression that it does so is just a trick of our psychological perspective. The battle lies between the supporters of the block universe, who assert that the true reality is the total and atemporal spacetime continuum, and the supporters of a temporal universe of true becoming, who affirm that the future is not yet in existence, as if waiting for us to arrive at it, but we play our part in bringing about its eventual form (see Isham and Polkinghorne 1993).

Einstein was a firm believer in the idea of the block universe, once speaking of the passage of time as being "only an illusion, if a stubborn one." Arguments often produced in support of this view are that (1) according to special relativity, different observers make different judgements of the simultaneity of distant events, so that distinction between past, present, and future cannot have a true significance; and (2) the equations of physics offer no lodging for the concept of the present moment. The proponents of the concept of a temporal universe of becoming respond that (1) all judgments of the simultaneity of distant events are intrinsically retrospective (the events must lie in the observer's past light cone before they can become known), so that the different accounts given of simultaneity amount to no more than different ways of organizing descriptions of what is unequivocally past, and therefore they can do nothing to establish the preexistent reality of the future; and (2) as for the present moment, so much the worse for physics if it finds no representation of such a basic human experience—only the most crassly physical reductionist could try to turn this deficiency of science into a source of metaphysical insight.

Moreover, while there is no universal "now" in local relativistic physics, when the observable universe is taken into account as a whole there is a natural frame of reference (at rest with respect to the cosmic background radiation), which is the frame cosmologists use when they say that the universe is 13.7 billion years old. Thus there is a possible candidate for a cosmic "now."

Before leaving the issue of time, it is important to emphasize that there is a clear logical distinction between questions of temporality and questions of causality. Believers in the block universe are not forced to commit themselves to a deterministic account of its causal structure. How the present state relates to the future is matter independent of whether that future already exists or not. It is interesting to note that a world of Laplacian determinism, in which past and future were necessary implications of the present, was nevertheless customarily thought of as a world of unfolding (inevitable) process.

CAUSALITY

Even more complex and contentious are the metaphysical questions of causality. The Scottish skeptical philosopher David Hume is notorious for having denied the concept of causality, affirming that all we can see in nature is constant conjunction. Yet the consistent following of event *A* by event *B* is surely an unintelligible regularity unless one makes the metaphysical assumption of a causal connection between them.

A number of points may be made about the relationship between physics and metaphysics in this connection.

1. Uncertainty of outcome may arise from two quite different kinds of physical effect: (a) ignorance of fine detail of the circumstances involved (the fall of a die is the canonical example of this in a Newtonian framework); (b) intrinsic indeterminism (as in quantum physics when it is interpreted in the Copenhagen tradition of Niels Bohr, which assigns a radical randomness to events such as the decay of a radioactive nucleus). Yet the inescapable role of metaphysical decision in settling issues of causality is clearly illustrated by the existence of David Bohm's alternative deterministic interpretation of quantum mechanics (Bohm and Hiley 1993), where Heisenberg's uncertainty principle is simply a principle of the necessary ignorance of certain parameters (hidden variables) whose values actually serve to complete the full determination of the outcome of events.

2. Physics' description of causal properties is patchy—good within certain regimes but with unresolved ignorance about how these different regimes relate to each other (Polkinghorne 2005, chap. 2). The paradigm example of this patchiness is the measurement problem in quantum mechanics (see Polkinghorne 2002, chap. 3). How does it come about that the cloudy and fitful quantum world, on each occasion of its interrogation by classical measuring apparatus, yields a definite answer—though not usually the same answer on each such occasion of interrogation? Various proposals have been made. In summary, the broad categories of explanation suggested are (a) It just happens as a matter of irreducible contingency; (b) Interaction with "large systems," which manifest irreversibility in their behavior, has the property of inducing a definite result; (c) Each possible result actually occurs, but different ones in the different branching worlds of a proliferating multiverse; (d) The intervention of the consciousness of an observer induces the effect. None of these proposals is wholly satisfac-

tory, and none commands universal assent. Thus a vital link between microscopic quantum physics and the classical-like world of macrophysics remains obscure. Problems become even more acute when classical systems with chaotic properties are involved (Berry 2001). Because of the fractal nature of the behavior of chaotic systems, their dynamics has a scale-free character. This implies that chaotic physics does not relate in any smooth way to quantum physics, which has a scale set by Planck's constant. Physics is very far from being able to describe a coherent and integrated account of process that would correspond to a seamless web of causal influence.

3. The intrinsic unpredictabilities in nature, discovered by twentieth-century physics first at the subatomic level of quantum theory and then at the everyday level of chaotic systems, offer opportunities to the metaphysician. Unpredictability is an epistemological property, and it is a matter for philosophical debate and decision to conclude what ontological properties are to be associated with it. Those of a realist cast of mind will tend to correlate epistemology closely with ontology, believing that what we know, or what we cannot know, is a reliable guide to what is the case. If this metascientific strategy is followed, unpredictability will be seen as the sign of a degree of causal openness in physical process. In the case of quantum theory, this is indeed the line that has been followed by the majority of physicists, who join with Bohr in interpreting Heisenberg's uncertainty principle as an ontological principle of indeterminism and not merely an epistemological principle of ignorance in the way that Bohm suggests. In the case of chaotic dynamics, however, this approach has been a less popular strategy. This seems to be at least partly because many take with undue seriousness the deterministic Newtonian equations from which the exquisitely sensitive solutions of chaos theory were first derived. Yet we know that these classical equations cannot be a correct description of the actual physical world. It is entirely possible, therefore, to treat the Newtonian equations as no more than "downward emergent" approximations to a more subtle and more supple reality. The essential condition for the approximate validity of this kind of classical physics is that entities can be considered as effectively isolatable from their environment. This is also the experimental situation in which Newton's equations have actually been subjected to practical verification, since in more complex situations one would face the impractical requirement of having to understand the totality of the context before one could begin to understand the particularity of the system under investigation. Yet, the sensitivity of chaotic systems implies that, in general, they are never truly isolatable from the slightest effects of their surroundings. There is, therefore, no valid obligation to adhere to the notion of deterministic chaos. Instead it is possible to be more bold in metaphysical speculation concerning the openness of such systems. This is an option that I have explored (Polkinghorne 1998, chap. 3).

4. Adopting such an option of openness by no means implies that we abandon the principle of sufficient reason, but merely that there is scope to consider the operation of additional causal principles beyond the conventional account of the exchange of energy between constituents that has been physics' standard approach. In the case of an ontological interpretation of chaos theory, one can see in broad terms the character that these additional principles may be expected to possess. Because chaotic systems are unisolatable, the new effects will be holistic in their character, relating to the whole rather than to the parts that make it up. The different possible future behaviors of a chaotic system do not differ in their total energy content but in the patterns in which that energy flows. Therefore, the new causal effects may be expected to relate to the specification of dynamical patterns of this kind. The novel feature proposed by the new paradigm does not relate to transfers of energy as such but to something one may call the input of "information," the specification of dynamical patterns of behavior. A concept of causal influence exercised through "active information" is thereby placed on the metaphysical agenda.

Speculative as these ideas necessarily are in our present state of knowledge, they gain some significant support from cognate phenomena encountered in other recent scientific developments. Encouragement to taking the concept of holistic information seriously comes from work on the emergent properties of logical networks studied by complexity theorists (Kauffman 1995) and from similar phenomena manifested by cellular automata (Wolfram 2001). Quite astonishing self-organizing principles are found to be acting in these systems, considered as totalities. However, such systems are logically determinate, so that in these cases the holistic properties observed must derive from a summation of lower-level effects. In physically realized complexity, such as in dissipative systems held far from thermal equilibrium through the exchange of energy and entropy with their environment, one also observes the unexpected spontaneous generation of large-scale patterns of ordered behavior (Prigogine and Stengers 1984). In this case, however, the arguments about physical openness given above permit the metaphysical possibility of there being truly holistic causal principles at work. Science is finding that "More is different," and Robert Laughlin (2005) has called for a revolutionary reinvention of physics that reverses the priority traditionally given to constituent theories over accounts of complex systems.

At the very least, it is clear that science has not succeeded in establishing the causal closure of the world in terms of its traditionally reductionist approach. The metascientific possibilities open to discussion are much too diverse and complicated for that to be a necessary conclusion. Moves in the direction of a metaphysically richer account gain further encouragement from the recognition that holistic forms of causality begin to offer some glimmer of understanding of how it might be that human agency is exercised. While great conceptual extension would be required before that ambitious goal seemed truly within our grasp, at least twenty-first–century science appears to be taking a small step toward describing a world of which we might actually be able to conceive ourselves to be inhabitants. This shift of understanding does not rely simply on an embrace of the relatively crude suggestion that agency might arise from direct and mysterious manipulations of quantum or chaotic uncertainties as such, but it stems from a recognition of the subtle and supple character of the causal nexus of the world, a property of which those uncertainties are symptoms. Finally, I would add that a universe of open process is one in which it is conceivable that that world's Creator interacts providentially with its history through the input of information into the open grain of natural causality (Polkinghorne 1998, chap. 3).

5. The appearance of holistic causal properties is a form of strong emergence (see Clayton 2004), whereby complex systems manifest a novel instrumental effectiveness beyond the consequences to be expected from a simple summation of the causal powers of the constituents that compose them. Other ways of seeking to approach the phenomenon of strong emergence have included appeals to notions of top-down causality (Peacocke 1993, 53–55, 157–60) and supervenience (Murphy 1999). However, since causality appears to be a zero-sum game, the actual causal power of higher-level concepts of this kind must remain problematic without a metascientific analysis that can offer reasons to believe that the lower-level causal effects do not by themselves account fully for the future behavior of the system (as would be the case for the logical models mentioned above). More has to be different in a way that is truly instrumental if there is to be the emergence of a deep kind of novelty. Just such an analysis has been attempted above in relation to the concept of physically active information.

GOD AND TIME

Metaphysical theories about the nature of time correlate with theological theories about how the eternal God relates to a temporal creation (Polkinghorne 2000, chap. 7). There are two distinct kinds of approach to the latter issue, each internally consistent on its own terms. They correspond to the insights of classical theology and of an open theology respectively. The difference between these theological stances is most clearly brought out by asking the question Does God know the future? Classical theology says Yes, and an open theology says No. Both forms of proposed answer are based on assent to two fundamental theological axioms: (1) God knows things as they actually are, that is, in accordance with their true nature; and (2) God knows all that can be known. Metaphysics exerts an influence on the discussion by giving content to the implications of these axioms. Different accounts of the nature of time will be consonant with different theological understandings.

The Block Universe. If the true nature of created reality is the atemporal spacetime continuum taken as a whole, according to axiom 1 God will know that atemporal reality according to its nature, that is, atemporally. This is precisely the understanding of classical theology, in the tradition stretching from Augustine and Boethius through Thomas Aquinas and on to Calvin and beyond. According to this view, the God who is wholly outside of time has the whole of creation's history laid out before the divine gaze, knowing every moment of that history *totum simul*—all at once. Thus, according to axiom 2, God knows what to us is the future, precisely because to the Creator all points of created time are "simultaneously" present. Recognition of the distinction already emphasized between the metaphysics of temporality and the metaphysics of causality implies that this total divine knowledge in no way imperils the freedom of action granted to creatures. God does not *fore*know the act of a free agent but simply knows it. What I do tomorrow is as contemporary to God as what I am doing now or did yesterday.

A Universe of Becoming. According to axiom 1, in such a world God knows temporal creatures according to their natures, that is to say temporally. This implies that God not only knows that events are successive but knows them in their succession. This requires a true divine engagement with time, the gracious acceptance by the eternal God of a temporal pole within the divine nature. (One might speculate that the divine frame of reference is that defining the cosmic "now.") Process theology speaks of such an eternal/temporal duality in God but regards it as being a metaphysical necessity that this should be so. However, those who do not subscribe to Whiteheadian metaphysics are at liberty to see the polarity of time and eternity in the divine nature as a consequence of the free kenotic act of God in choosing to relate to a temporal creation in this way. Certainly the concept is one that is consonant with the biblical picture of a God thoroughly involved in the unfolding history of Israel and embracing a radical engagement with time in the episode of the Incarnation. In a world of true becoming, the future does not yet exist, and so axiom 2 implies that even God does not yet know that future and that this is in no way an imperfection of the divine nature since it is not yet available to be known.

The unavoidable role played by metaphysical considerations in settling issues of space, time, and causality makes it perfectly proper for theology to give its support to particular proposals that it finds consonant with its understanding of the nature of the Creator and of creation. Classical theology is free to endorse the concept of the block universe, and open theology is free to endorse the concept of a temporal universe of becoming.

Note

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References

Berry, Michael. 2001. "Chaos and the Semiclassical Limit of Quantum Mechanics." In *Quantum Mechanics*, ed. Robert John Russell, Philip Clayton, Kirk Wegter-McNelly, and John Polkinghorne, 41–54. Notre Dame, Ind.: Univ. of Notre Dame Press.

Bohm, David, and Basil Hiley. 1993. *The Undivided Universe.* London: Routledge.

Clayton, Philip. 2004. *Mind and Emergence.* Oxford: Oxford Univ. Press.

Isham, Christopher, and John Polkinghorne. 1993. "The Debate over the Block Universe." In *Quantum Cosmology and the Laws of Nature*, ed. Robert John Russell, Nancey Murphy, and C. J. Isham, 135–44. Notre Dame, Ind.: Univ. of Notre Dame Press.

Kauffman, Stuart. 1995. *At Home in the Universe.* New York: Oxford Univ. Press.

Laughlin, Robert. 2005. *A Different Universe.* New York: Basic Books.

Murphy, Nancey. 1999. "Supervenience and the Downward Efficacy of the Mental." In *Neuroscience and the Person*, ed. Robert John Russell, Nancey Murphy, Theo C. Meyering, and Michael Arbib, 147–64. Notre Dame, Ind.: Univ. of Notre Dame Press.

Peacocke, Arthur. 1993. *Theology for a Scientific Age*. Oxford: Oxford Univ. Press.

Polkinghorne, John. 1998. *Belief in God in an Age of Science.* New Haven: Yale Univ. Press.

———. 2000. *Faith, Science and Understanding.* London: SPCK, and New Haven: Yale Univ. Press.

———. 2002. *Quantum Theory: A Very Short Introduction.* Oxford: Oxford Univ. Press.

———. 2005. *Exploring Reality.* London: SPCK, and New Haven: Yale Univ. Press.

Prigogine, Ilya, and Isabelle Stengers. 1984. *Order out of Chaos.* London: Heinemann.

Wolfram, Stephen. 2001. *A New Kind of Science*. Champaign, Ill.: Wolfram Media.