2

Causation and Laws of Nature

2.1 Introduction

In this chapter and the next, I shall explain the notions of causality and the laws of nature which are fundamental for KCA-TA (Kalām Cosmological Argument-Teleological Argument), and defend the Causal Principle 'whatever begins to exist has a cause'. The defence of the Causal Principle is very important for philosophy of religion debates and science and religion dialogues, as it provides the basis for a response to Hawking's claim that

> You can't get to a time before the Big Bang because there was no time before the Big Bang. We have finally found something that doesn't have a cause, because there was no time for a cause to exist in. For me this means that there is no possibility of a creator, because there is no time for a creator to have existed in. (Hawking 2018, p. 38)

I shall respond to Hawking's claim in Chap. 6 after establishing the Causal Principle in Chaps. 2 and 3.

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In his *Inquiry and Essays*, the eighteenth-century philosopher Thomas Reid (1710–1796) declared 'that neither existence, nor any mode of existence, can begin without an efficient cause, is a principle that appears very early in the mind of man; and it is so universal, and so firmly rooted in human nature, that the most determined scepticism cannot eradicate it' (Reid 1983, p. 330). His contemporary and well-known sceptic David Hume had apparently raised an objection by claiming that the ideas of cause and effect are distinct and we can conceive of an uncaused beginning-to-be of an object (Hume 1739/1978, p. 79). However, Hume confessed in a letter written in 1754 that 'I never asserted so absurd a Proposition as that anything might arise without a cause: I only maintain'd that, our Certainty of the Falsehood of that Proposition proceeded neither from Intuition nor Demonstration; but from another Source' (Hume 1932, i., p. 187). Thus, it seems that Hume himself would agree that the mere conceivability of something beginning to exist uncaused does not provide sufficient grounds for rejecting the principle stated by Reid (Anscombe 1974). Others however have argued that (in the absence of arguments to the contrary) conceivability does entail possibility, and philosophers influenced by Hume have raised doubts about Reid's principle. For example, in the Preface to the Second Edition of his *Critique of Pure Reason*, Immanuel Kant argued that, while the principle of causality is valid for objects as phenomena, it may not be valid for objects as things in themselves (the noumenal world). In more recent years, some scientists and philosophers have claimed that quantum physics indicate that uncaused events happen all the time (Grünbaum 2009, p. 15). It has also been argued that, even if things do not begin to exist uncaused within our universe, it might be the case that our universe itself begun to exist uncaused (Oppy 2010, 2015; Almeida 2018).

The debate is fascinating and of importance to metaphysics, philosophy of science, philosophy of religion, and science and religion dialogues. In this book, instead of defending the stronger claim that 'neither existence, nor any mode of existence, *can* begin without an efficient cause' (Reid), I shall defend the weaker claim that 'neither existence, nor any mode of existence, begins without a cause', that is, 'whatever begins to exist has a cause' (here, the word 'cause' refers to either an efficient cause or a material cause; I shall explain this point below). For convenience of exposition, I shall henceforth refer to this weaker claim as *the* Causal Principle. I shall first define the key terms of the Causal Principle in the next section, and then respond to some objections to the Causal Principle. In the next chapter, I shall defend an argument in support of the Causal Principle. I shall show that the Causal Principle remains defensible not only on the dynamic (A-) theory of time but also on the static (B-) theory of time (which is widely accepted by cosmologists).

2.2 Defining the Key Terms of the Causal Principle

I shall begin by discussing the definitions of the key terms of the Causal Principle 'whatever begins to exist has a cause' and the related terms 'time', 'eternal', 'event', 'change', 'perdurantism', and 'uncaused'.

'Whatever' refers to all that exists (regardless of whether they are things, events, substances, states of affairs, arrangements, etc.). Some have objected to the Causal Principle by claiming that everything came from pre-existent materials (e.g. my body came from pre-existent molecules) and therefore there isn't anything which begins to exist. Those who affirm *creatio ex nihilo* (according to which God is the efficient cause who brought about the universe without material cause) would dispute the claim that everything came from pre-existent materials, but in any case the objection is based on a misunderstanding, since 'whatever' refers to events and arrangements as well. (Thus, for example, even though my body came from pre-existent molecules, there was a beginning to the event at which the molecules constituted the first cell of my body resulting in a new arrangement of the molecules. The event and new arrangement were *caused* by the fertilization of my mother's egg by my father's sperm.) Therefore, the Causal Principle does not require the demonstration of *creatio ex nihilo* (nor does it deny *creatio ex nihilo*; see below). Rather, the Causal Principle is claiming that, regardless of whether something begins from pre-existing materials or not, it has a cause.

'Begins to exist': something has a beginning if it has a temporal extension, the extension is finite,[1] and it has temporal edges/boundaries, that is, it does not have a static closed loop (see Chap. 5) or a changeless/timeless phase (see Chap. 6) that avoids an edge. Consider, for example, Oppy's defence of the claim (against Craig) that it is possible for the initial state of reality to *come into existence* uncaused *out of nothing* (Oppy 2015, section 4, italics mine). The terms in italics indicate a temporal boundary, that is, a beginning. Whereas on Craig's theistic hypothesis, God (the First Cause) does not come into existence uncaused out of nothing; rather, God is timeless sans creation and in time with creation (Craig and Sinclair 2009, p. 189). On this view, God's existence has a timeless phase which avoids a boundary and is therefore beginningless.

In relation to the definition of 'beginning', there are different views of time which need to be distinguished. A relational view of time defines time as an extended series of changes/events ordered by 'earlier than' and 'later than' relations, whereas a substantival view of time affirms that time can exist as an extended substance independently of change.

According to the dynamic (A-) theory of time, the members of a series of changes/events come to be one after another. Whereas on the static (B-) theory of time, our spacetime is a four-dimensional block and the series of events is a tenselessly existing manifold all of whose members are equally real and the 'flow' of time is regarded as illusory. By defining 'beginning to exist' in terms of 'temporal extension' and 'boundary', I am using a definition that is compatible with both static and dynamic theories of time.

Against some philosophers who have doubted the existence of time altogether (Pelczar 2015), Simon (2015) notes that 'it would suffice if we could know via a combination of introspection and memory that our experience changes. But this is commonplace: I remember that I was experiencing a sunrise, and I introspect that I no longer am.' Moreover, 'it would suffice if we could conclude that experiences *take time* … in the words of Ray Cummings (1922), 'time is what keeps everything from happening all at once' (ibid.). Thus, the fact that I do not hear all the notes of a Beethoven symphony all at once is evidence that events do not happen all at once; rather, there is a sequence. It has sometimes been claimed that a massless particle travelling at the speed of light is 'timeless'. However, what this means is that according to Special Relativity, something travelling at the speed of light would not 'experience' time passing.

One needs to note the distinction between experience and reality. Even though a massless particle travelling at the speed of light does not 'experience' time passing, in reality it still has a beginning in time at its point of origin from where the particle is emitted. (For the discussion on timelessness, see further, Chap. 6.)

There are also different uses of the word 'eternal' which need to be distinguished. 'Eternal' can mean (1) having no beginning and no end; however, 'eternal' has also been used in the literature to refer to (2) something that does not come into being or go out of being. On the static theory of time, the universe can have a beginning (in the sense explained above) and thus is not eternal in the first sense, and yet does not come into being or go out of being, and thus is eternal in the second sense. In line with the latter usage, 'eternalism' is used in the literature to refer to the view that our spacetime is a four-dimensional block and the series of events is a tenselessly existing manifold all of whose members are equally real. However, one must be careful to note that this does not imply that the universe has no beginning. (Moreover, 'eternal' has also been used to refer to (3) something that has no end but has a beginning; for example, Vilenkin affirms 'eternal inflation' and yet he argues that the universe has a beginning; see Chap. 4.)

An event is understood as a change. The existence of changes is undeniable. It is true that according to the B-theory of time, the 'moving present' (often called the 'flow of time') which we experience in our consciousness is regarded as illusory. (Because of this, the static theory of time is sometimes misleadingly regarded as timelessness or changelessness. The key issue concerns the definition of time and change; see below.) Nevertheless, no time-theorist (whether A- or B-theorist) would deny (for example) that he/she has undergone numerous changes since he/she was conceived (e.g. he/she has grown taller, heavier, etc.). Nathan Oaklander (2004, p. 39) observes, 'The rock-bottom feature of time that must be accepted on all sides is that there is change, and the different views concerning the nature of change constitute the difference between A- and B- theories of time.'

A change is understood here as involving a thing or part of a thing[2] gaining or losing one or more properties. On a dynamic (A) theory of time, the gaining/losing of properties involves a coming to be/passing away of properties. On a static (B) theory of time, the gaining/losing of properties does not involve a coming to be/passing away of properties; rather, it involves having different temporal parts at different times (perdurantism). The different parts have boundaries and hence beginnings (see the definition of 'beginning' above).

Thus, it is true that on a static theory, a four-dimensional block is 'unchanging' if this is understood as saying that there is no coming to be/passing away of properties, and that there is no 'earlier' event if this is understood as saying that there is no event that passes away before others. However, as Oaklander observes, there are still changes in the sense that the four-dimensional block has different temporal parts with different properties at different times. Moreover, some parts (e.g. those temporal parts in which there is water on earth) are posterior to ('later' in this sense) and dependent on prior ('earlier' in this sense) temporal parts (e.g. those temporal parts in which there is formation of hydrogen near the beginning of the Big Bang; scientists would say that the formation of water is dependent on the prior existence of hydrogen). In this sense later events are dependent on earlier events, and this remains true on the block theory. On a static theory of time, every event in the 'block' exists and is equally real, but nevertheless 'later' events are still dependent on 'earlier' events. Indeed, any theory of time which denies such a basic scientific fact as the formation of water in our universe is dependent on the prior existence of hydrogen would have to be rejected, and no B-theorist of time would deny that. (The dependence can be characterized using counterfactuals as follows: 'if there were no hydrogen formed earlier, there would not be water formed later'; I shall argue below that this dependence is causal.)

It might be objected that, while it makes sense to talk about things 'beginning to exist' within the spacetime block on B-theory of time, it makes no sense whatsoever to talk about the block itself beginning to exist.[3] But this is not true; if the spacetime block is finite in temporal extension etc. ('etc.' refers to 'does not have a static closed loop or a changeless phase that avoids an edge'), then that implies that the spacetime block has a beginning—the same sense of 'beginning to exist' is used. While the spacetime block does not 'come to be' on this B-theory view,[4] it still has a beginning in the sense of being finite in temporal extension etc., just as every part of it has a beginning in the sense of being finite in temporal extension etc. Craig and Sinclair (2009, p. 183) note that 'For B-Theorists deny that in beginning to exist the universe came into being or became actual'. Note that the concept of 'beginning to exist' is not absent in B-theory; indeed, scientists who are B-theorists (e.g. Carroll 2014) frequently speak about the beginning of universe. On B-theory 'beginning to exist' is not understood as 'came into being or became actual', but it is defined as 'exists tenselessly as a four-dimensional space-time block that is finitely extended' (Craig and Sinclair 2009, p. 184). The claim that 'the block does not exist in time thus to talk about a beginning is meaningless' is therefore false; regardless of whether the block exists in time or not, if it is finitely extended etc. then it has a beginning according to the static theory's definition of beginning. A block by definition has extension and an extension can be finite etc. One can say that the part of the spacetime block in which (say) Einstein exists is finite in the sense that it did not consist of an actual infinite moments but is finite etc. That is what it means to say that the block itself has a beginning.

One might object that there is a difference between the part of the block in which Einstein exists and the whole block itself, namely, the whole block itself does not exist in another time block whereas Einstein would exist in the time block. Nevertheless, I shall argue in Chap. 3 that, if the whole block has a beginning, it would have a cause just as the part of the block in which Einstein exists has a cause, the only difference is that, if the cause of the block is initially timeless (see Chap. 6), then it is not earlier than the block whereas the causes of Einstein (e.g. his parents) are earlier than Einstein. Both would still have causes, however.

One might ask how can the block have a cause if (according to static theory) it does not come into being or become actual, even though it has a beginning. In reply, the part of the block in which Einstein exists also does not come into being or become actual on the static theory, yet his existence is still causally dependent on his parents' existence in the sense that, if his parents had not existed, Einstein would not begin to exist. Likewise, I shall argue in Chap. 3 that the whole spacetime block has a cause in the sense that, if the cause does not exist, the spacetime block would not begin to exist.

Aristotle (*Physics* 2.3) famously identified four kinds of causes: efficient cause (the source of change, for example, the sculptor's act of bronze-casting the statue), material cause ('that out of which a thing comes to be and which persists', for example, the bronze of the statue), formal cause ('the form or the archetype', for example, the structure of the statue), and final cause ('in the sense of end [telos] or that for the sake of which', for example, the sculptor sculpting the statue for aesthetic purposes) (Mackie 2005). In this book, unless otherwise stated, 'cause' refers to either an efficient cause or a material cause, and which is either necessary or sufficient[5] for an effect,[6] understood as a change.[7] Weaver (2019, p. 261) notes that causation is multigrade, asymmetric (although not always temporally asymmetric), transitive, irreflexive and a dependence relation: 'when event *x* causes event *y*, *y* depends for its existence and contingent content on *x*.'[8]

Finally, there are two different senses of the phrase 'begins uncaused' which are often used in the literature and which should be distinguished:

(1) For any *x*, if *x* begins uncaused, then the beginning of *x* does not have a causally necessary condition understood as either an efficient cause or material cause. That is, either

(1.1) *x* begins without any causally necessary condition at all, or

(1.2) *x* begins without something that is known to be a causally necessary condition (under certain circumstances) for the beginning of *x*. For example, in the reality that we now inhabit, what is causally necessary for an increase in strength of a pre-existent electric field under certain circumstances would include (for example) the switching on of an electric field generator. If events such as the increase in strength of pre-existent electric fields happen without the switching on of electric field generators under the same circumstances, they would be regarded as uncaused and would entail a chaotic world e.g. I would suffer from electric shock even though nothing is switched on (see Chap. 3).

(2) Indeterministic events, such as (as many physicists would affirm) quantum events and (as many libertarians would affirm) a genuinely free act. It is controversial whether humans have libertarian freedom and whether quantum events are genuinely indeterministic. In any case, it should be noted that a libertarian free act does not imply that there is no causally necessary condition for the making of it; the pre-existence of the agent, for example, would be a causally necessary condition. Likewise, the

pre-existence of quantum field (for example) would be a causally necessary condition for quantum fluctuation while the pre-existence of atomic nuclei and the so-called weak nuclear force would be causally necessary conditions for beta-decay, in the absence of which the beta-decay would not occur (Bussey 2013, p. 20). The difference between supposed quantum indeterminism and (say) the supposed uncaused increase in strength of a pre-existent electric field in (1) above is that the former lacks a causally sufficient condition whereas the latter lacks a causally necessary condition.

In this book, unless otherwise specified, 'uncaused' is understood in the first sense, which is consistent with a key motivation for the Causal Principle, namely, *Ex Nihilo Nihil Fit* ('from nothing, nothing comes'). A genuinely free act would not be 'from nothing'; rather, it is from the agent (see further, Chaps. 3 and 6).

The conviction that 'from nothing, nothing comes' led Aristotle to insist that every state of the world must have come from a previous state of the world and hence the world must be everlasting (Cogliati 2010, p. 7)—this insistence resulted in the denial of the Christian doctrine of *creatio ex nihilo* among many ancient philosophers. However, such an insistence is unwarranted given the distinction between efficient cause and material cause. *Creatio ex nihilo* only denies that the world has a material cause; it does not deny that the world has an efficient cause. On the contrary, '*creatio*' implies that the Creator is the efficient cause who brought about the universe; in this sense, the world is from God and not from nothing.

Aristotle might object that 'from nothing, nothing comes' applies to material cause as well, and insist that 'from no material cause, nothing comes'. He might appeal to our daily experiences, which seem to support the inductive generalization that whatever begins to exist has a material cause. Craig replies that such an inductive generalization can be treated merely as an accidental generalization, 'akin to human beings have always lived on the Earth, which was true until 1968. The univocal concept of "cause" is the concept of something which brings its effects, and whether it involves transformation of already existing materials or creation out of nothing is an incidental question' (Craig and Sinclair 2009, pp. 188–9, 195). On the one hand, there has been no compelling argument offered to show that causes must involve the transformation of already existing materials. On the other hand, God as a causal agent could have causal powers that other entities (e.g. humans) do not have. While humans, for example, require pre-existing materials to work from in order to create (say) a table, God does not require that.[9] Moreover, there are independent arguments for the Causal Principle (see Chap. 3). Note, in particular, that the Modus Tollens argument for this principle explained in Chap. 3 is not dependent on inductive considerations, and because of this additional argument, the Causal Principle enjoys greater support than the principle that 'whatever begins to exist has a material cause', which, in any case, can be regarded as an accidental generalization, as Craig argues. In light of this, the affirmation that there is no physical entity prior to $t = 0$ only implies that the universe was not created out of pre-existent material; it does not imply that there cannot be an efficient cause which has the power to bring about the universe without requiring material cause. To insist otherwise would be to beg the question against *creatio ex nihilo* (see further, Chap. 6).

2.3 Causation, Fundamental Physics, and Laws of Nature

Causal eliminativists affirm that there are no obtaining causal relations in the mind-independent world (Weaver 2019, p. 24), while causal reductionists affirm that causation reduces to something else such as a law-governed physical history, where both the laws and physical history are non-causal (Weaver 2019, p. 62).

In favour of causal eliminativism, it might be thought that causes are merely human interpretations which involve concepts and modelling. However, if one takes up a piece of wood and hit one's head, one would realize that, while the application of the concept of cause to the wood may be a human interpretation, the wood does have real power to bring about the event of pain, and the correlation is real. Weaver (2019, p. 90) observes that instances of sensation and sense perception involve obtaining causal relations (the environment impressing itself upon the senses).

Moreover, the formation of beliefs implies that there are obtaining causal relations because formations are causal phenomena. ‘When a cognizer forms a thought, they relate to the thought through causation. When a cognizer forms a desire, they cause (perhaps together with other factors) the desire’ (p. 93).

While Bertrand Russell (1918) had declared causation to be a scientifically obsolete notion and logical positivists had tried to build philosophical systems without any reference to cause and effect, Koons and Pickavance (2015, p. 8) observe that

> Since then, causation has reclaimed its status as a central notion in philosophical theory. Edmund Gettier, in a famous article in 1963, challenged the traditional definition of knowledge as justified true belief, leading to new theories of knowledge that relied upon some kind of causal connection between states of knowledge and the world. Modern theories of sensory perception and memory, in particular, require reference to appropriate causal mechanisms. Work in the philosophy of language by Keith Donnellan, Saul Kripke, and Gareth Evans, among others, introduced causal theories of the meanings of words and the content of thought. Finally, the philosopher of science Nancy Cartwright demonstrated that causation is far from obsolete in the experimental sciences.

Causal reductionists such as cosmologist Sean Carroll (2014) claim that ‘the notion of a “cause” isn’t part of an appropriate vocabulary to use for discussing fundamental physics. Rather, modern physical models take the form of unbreakable patterns—laws of Nature—that persist without any external causes.’ Carroll thinks that our construction of causal explanations for objects within the totality of physical reality is due to the fact that the objects obey the laws of physics, and that there is a low-entropy boundary condition in the past.[10] However, there is no physical law and no low-entropy boundary condition that apply to the totality of physical reality itself; hence, we have no ‘right to demand some kind of external cause’ (Carroll and Craig 2016, pp. 67–8).

In reply, it should be asked why the ‘patterns’ Carroll refers to are ‘unbreakable’. While Carroll appeals to the so-called laws of nature, one should ask why the events described by fundamental physics follow those laws.

Now Hume famously stated that the laws of nature are simply regularities of events; there is no relationship of necessity between these events, nor are laws conceived of as something that govern the regularities. Hume also claims that 'we may define a cause to be an object, followed by another, and where all the objects similar to the first, are followed by objects similar to the second', and that 'all events seem entirely loose and separate' (*An Enquiry concerning Human Understanding* 1748, section VII). Following Hume, Regularity Theorists of Causation have analysed causation as regular patterns of succession and have regarded these regularities as 'brute facts' rather than as something in need of an explanation. Against this, others have argued that the question 'Why is the world regular (in the particular way that it is)?' needs to be answered by a deeper explanation, for otherwise the regularity of event *P* followed by event *Q* (rather than, say, event *R*, or *S*, or *T*, etc.) is just due to chance, which is highly improbable (Strawson 1989, pp. 205–6). I shall argue below that the deeper explanation is provided by the properties of the things which are involved in these regular patterns, and these properties can be called 'causal properties'.[11]

Regularity Theorists might object that the question 'What explains the regularity?' is merely pushed back on Strawson's strategy. For example, if the deeper explanation offered is 'Because of the nature of matter', they may ask 'what explains the nature of matter (or whatever)?' Since there must after all be some terminus of explanation, why not terminate with the regularities themselves (Psillos 2009, pp. 134–135)?

In reply, I would argue that terminating with regularities does not get rid of the problem of the improbability of one event following another regularly by chance. On the other hand, terminating with an alternative explanation such as 'because of causal properties grounded in the nature of matter', which, one might argue, is determined by a beginningless and uncaused First Cause (see Chap. 6) and therefore not the result of chance, would resolve this problem.

Carroll might insist that in fundamental physics, 'real patterns' described by laws explain causal regularities, but the question is, why the events described by fundamental physics follow those patterns/laws? A pattern/law of nature is not a concrete thing but merely a description of behaviour of concrete events/thing; thus, it is still the properties of those concrete event/things which ground the behaviour/law, and those properties can be called causal properties. As Feser (2013, p. 254) observes, the laws of nature are 'mere abstractions and thus cannot by themselves explain anything. What exist in the natural order are concrete material substances with certain essences, and talk of "laws of nature" is merely shorthand for the patterns of behavior they tend to exhibit given those essences.' Against Maudlin (2007), Dorato and Esfeld (2014) argue that the view that laws are grounded in properties (global properties rather than 'intrinsic' or local properties, in view of quantum entanglement) makes intelligible how laws can 'govern' the behaviour of objects. This is the decisive advantage of dispositionalism over primitivism (the view that laws are primitive).

Carroll might object that the equations of fundamental physics do not seem to specify which events are the causes and which events are the effects. Ladyman et al. (2007, p. 160) claim that 'matter has become increasingly ephemeral in modern physics, losing its connection with the impenetrable stuff that populates the everyday world … the ontology of modern physics seems to be increasingly abstract and mathematical'. Weaver (2019, p. 63) notes that the reason why causal eliminativism has been so prevalent in philosophy of physics 'is connected to a tendency in that sub-discipline to associate the substantial content of physical theories with the mathematical formalisms of those theories … because formalisms do not contain any causal notions … physical theories should not be understood causally'.

Nevertheless, Weaver also observes that many great physicists past and present, including the discoverers of relativity and quantum mechanics, 'adopted causal approaches to physics and conceived of their inquiry as a searching evaluation of the world that should uncover causes' (Weaver 2019, p. 71). The equations of fundamental physics do not specify causality because they do not provide an exhaustive description of reality. Consider the following example which illustrates that mathematical equations do not provide a complete account of the natural world and that an interpretative framework involving causal considerations is required: The quadratic equation $x^2 - 4 = 0$ can have two mathematically consistent results for '*x*': 2 or −2. Both answers are mathematically possible. However, if the question is 'How many people carried the computer home?', the answer cannot be '−2', because in the concrete world it is metaphysically impossible that '−2 people' carry a computer home, regardless of what the mathematical equation shows. The impossibility is metaphysical, not mathematical, and it illustrates that metaphysical issues are more fundamental than mathematics. The conclusion that '2 people' rather than '−2 people' carried the computer home is not derived from mathematical equations, but from causal considerations: '−2 people' lack the causal powers to carry a computer home.

Feser (2017, pp. 45–46) observes that 'since the equations of physics are, by themselves, mere equations, mere abstractions, we know that there must be something more to the world than what they describe. There must be something that makes it the case that the world actually operates in accordance with the equations, rather than some other equations or no equations at all.' In other words, the equations of physics merely provide an incomplete description of regularities without ruling out efficient causation and causal properties which (as explained above) operate at a more fundamental level as the ground of these regularities.

A number of concerns have been raised in the literature regarding the temporal order of events. It has been claimed that the Delayed Choice Quantum Eraser violates the notion that causes cannot be later than their effects. To elaborate on one version of this Eraser, according to the so-called Copenhagen interpretation of quantum mechanics, the photon either behaves as a wave or a particle when it passes through the double slit, and if scientists quickly place a detection device, the device would detect a particle, if not, a wave behaviour would be observed. Since the placement of the detection device happens after the photon passed through the double slit, it seems that the placement of the detection device determined what happened earlier (whether the photon would behave as wave or particle). However, this reasoning assumes the Copenhagen interpretation. According to Bohm's interpretation, the photon is always a particle guided by wave (the particle follows one path, while its associated wave goes through both paths); thus, the placement of the detection device did not determine what happened earlier but merely what happened to the photon at the moment of detection (Bricmont 2017, p. 145).

It has also been claimed that recent experiments in quantum mechanics (a photon prepared in a superposition with regard to its polarization hitting point A before point B on one route while hitting B before A on the other route; these two causal paths [A then B, or B then A] are in superposition) has indicated that, at the fundamental level, temporal order is not fixed (Indefinite Causal Order) (Qureshi-Hurst and Pearson 2020). However, the problem is that such claim assumes the Copenhagen interpretation, which (as explained previously) is unproven. Moreover, as explained previously in Chap. 1, instead of thinking of the superposed state as a photon existing in contradictory states, one can think of it as a quantum of energy spread across the possible states as a wave. Some parts of the wave reach A before B, while other (different) parts of the wave reach B before A; there is no contradiction and no violation of temporal order (it should also be noted that the emission of the photon happens before A or B: a definite temporal order!).

With regard to the so-called backward in time travelling positron in QED, this may be interpreted (in accordance with Paul Dirac's hole theory) as spacetime locations in the Dirac sea (a theoretical model of the vacuum as a sea of particles with negative energy) at which a negatively charged electron comes into being carrying the negative energy imputed to it by the Dirac sea (Greiner and Reinhardt 2009, p. 40), thus there is no violation of temporal order.

In any case, as I explain in response to Linford below, even if backward causation is possible and that it is the case that the future determines the past, given the arguments that the future is finite and that a closed loop is impossible (Chap. 5), the 'last' duration of the future would be the first, and the rest of my argument would still follow. Thus, in any case, the Cosmological Argument I defend is not affected by the above-mentioned concerns regarding the temporal order of events.

Ladyman et al. (2007, p. 160) claim that causation is problematic in the microscopic domain where, for example, 'the singlet state in the Einstein-Podolsky-Rosen (Bohm-EPR) experiment fails to screen off the correlations between the results in the two wings of the apparatus, and thus fails to satisfy the principle of the common cause'. In reply, Bohmian mechanics and the Ghirardi, Rimini and Weber (GRW) mass density theory are able to offer a causal explanation of the correlated outcomes of EPR-type experiments in terms of a non-local common cause (Egg and Esfeld 2014).

It might be objected that, 'from the point of view of microphysics, given an individual event, there is no objective distinction between which events make up that event's past and which its future. Therefore, there is no microphysical distinction between which are its causes and which its effects. Thus, there are no facts about microphysical causation' (Ney 2016, p. 146). Linford (2020) claims that 'efficient causation is a time asymmetric phenomenon' (p. 8)', but 'the direction of time does not appear in our best microphysical theories' (p. 4). He states that 'the distinction between the past and the future made in fundamental physics (if fundamental physics really does distinguish the past from the future) are unlikely to explain the distinction between causes and their effects or any of the other macrophysically observable temporal asymmetries' (n.4). Linford notes that 'the project of explaining all temporal asymmetry—including the asymmetry of efficient causation—in terms of the Mentaculus is ongoing', and if successful, 'efficient causation, qua macrophysical time asymmetry, will be given a reductive explanation in terms of the Mentaculus' (p. 8). Linford explains that the 'Mentaculus' hypothesis (which is part of what he calls the 'Albert–Loewer–Papineau reductive programme', or ALP) consists of the conjunction of three principles:

> First, whatever the fundamental dynamical laws happen to be. Second, the Past Hypothesis, that is, the hypothesis that the universe began in the low entropy macrophysical state … third, the Statistical Postulate, that is, the specification of a uniform probability measure over the portion of phase space consistent with whatever information we happen to have about the physical world. (pp. 7–8)

The implication of this project (if successful) is that

> Even if the coming into being of E requires explanatorily prior, physically necessary conditions C … the explanatorily prior, physically necessary conditions need not fall in any particular temporal direction with respect to E … the explanatorily prior and physically necessary conditions for the universe's 'beginning' can fall in the temporal direction away from the

> beginning … entities do not require explanatorily prior or simultaneous causes for their coming into being. (p. 11)

In reply, first, it does not follow from the fact that microphysics is not able to distinguish between past and future events that there are no facts about microphysical causation. The reason is that it might be the case that microphysics does not provide a complete explanation of microphysical reality, but only a certain aspect of it, and therefore what cannot be discerned from physics does not imply it does not exist.

Second, the underlying assumption of the above arguments is the Humean assumption that the direction of causation is parasitic on temporal direction, but this assumption can be challenged (see further, below and Chap. 3).

Third, an explicitly causal theory of quantum gravity has been proposed (Wall 2013a, b). While the correct framework for a truly quantum theory of gravity is far from settled, the current status of quantum gravity studies suggests that 'any case for the claim "quantum gravitational physics does not need causation" is at best uncertain and incomplete' (Weaver 2019, p. 274).

Fourth, Frisch points out that descriptions in scientific literature support the thesis that 'even at the level of fundamental research in physics, our conception of the world is ineliminably causal' (Frisch 2014, p. 66). He cites as an example a report from the Large Hadron Collider study group of CERN which mentions that

> There are various places in the machine where beams can be 'injected,' that other components allow 'suppression' of dispersion, and that others allow for the 'cleanup' of the beam. Finally, there is the 'beam dump' where the beam can be deposited with the help of 'kickers.' In the detector, when a photon passes through matter, it 'knocks out' electrons from the atoms 'disturbing the structure of the material' and 'creating' loose electrons. (Ibid., citing Pettersson and Lefèvre 1995)

Frisch rightly concludes that, although the word 'cause' is not used in these descriptions, the terms he quoted all describe what Nancy Cartwright would characterize as 'concretely fitted out' instances of 'causings' (Frisch 2014, p. 66). The fundamental particles described by nuclear physics clearly have dispositional properties, that is, tendencies to produce certain effects when they interact in certain ways (Martin 2008, p. 50).

Weaver (2019, p. 124) notes that 'the word interaction in scientific and physical research contexts is a causal term', citing the *Oxford Dictionary of Physics*, which gives the technical definition: An interaction is 'an effect involving a number of bodies, particles, or systems as a result of which some physical or chemical change takes place to one or more of them'. Weaver (2019, p. 234) observes that 'There are four fundamental types of interactions between fundamental entities in our best physical theories, viz., the strong, weak, electromagnetic, and gravitational interactions … No one (so far as I'm aware) in the physics literature denies that all four types of physical phenomena are interactive phenomena.'

Weaver also notes that, if there is causation in the physical base, then 'any attempt to reduce causal direction to the arrow of entropic increase, for example, will fail, for already within microphysical evolutions driving entropic increase are obtaining causal relations and therefore causal direction' (p. 131). Hence, it has not been shown that causal direction reduces to some direction in a non-causally interpreted physics given that what's fundamental in one of our currently best quantum theories should be interpreted causally (p. 143).

One might worry that the view that time-reversal invariant[12] entails that there are naturally possible worlds at which the imagined microdynamical causes are the effects whereas the effects are transmuted into the causes. In reply, Weaver (2019, p. 133) argues concerning the proposition 'every purely contingent event has a causal explanation featuring an obtaining irreflexive causal relation to back it' that a binary relation being necessarily asymmetric does not entail that the relation goes the same way in all possible worlds. It does not rule out the possibility that, if a gluon's activity causes a quark to take on certain properties in our world, the quark's beginning to exemplify those properties is the cause of the gluon's activity in another possible world. In other words, while the relationship between cause and effect is necessarily asymmetric, this does not imply that the kind of thing *x* which is the cause for an effect *y* in this world cannot be an effect *y* of cause *x* in another possible world. 'If at an arbitrary world *w*, the gluon's activity causes a quark to take on certain properties, then (at *w*) it is not the case that the quark's taking on those properties causes the gluon's activity' (ibid.). Additionally, there is a deductive argument for Causal Principle which shows that whatever begins to exist (this would include events at the level of fundamental physics) has a cause (see Chap. 3); therefore, causality is fundamental.

Concerning Norton (2003)'s 'mass on the dome' thought experiment, it does not pose a problem for my argument because the thought experiment (even if successful; this has been challenged by other philosophers) only goes to show that Newtonian mechanics is consistent with uncaused events. It does not show that uncaused events do happen. One can legitimately reply that, on the one hand, Newtonian mechanics is not a complete description of physical world (indeed, given quantum physics and relativity, we know it is not). On the other hand, given my Modus Tollens argument (see Chap. 3), we know that events do not happen without causally necessary condition(s). Additionally, Norton's thought experiment also assumes that time is composed of instants; but as Craig and others have argued, this view should be rejected because it results in paradoxes of motion (see Chap. 5).

Another problem with the Humean view of causation is that contingent relations between events would not support counterfactuals and warrant predictions in science (Mumford 2004, pp. 161–162). Thus, following Kripke (1980), who argues that there are metaphysical necessary truths discovered *a posteriori* (e.g. water is H_2O), many contemporary philosophers of science have argued that there are causally necessary connections between causal relata (such as events, substances, or states of affairs). The laws of nature have been regarded by them to be at least partly metaphysically necessary (necessitarian view; see, for example, Ellis 2001; Bird 2007), while other philosophers regard them as metaphysically contingent overall (contingentist view; see, for example, Fine 2002; Lowe 2002). Alternatively, one might deny that the laws of nature obtain with metaphysical necessity but argue that there is nevertheless a particular sense of necessity pertaining to natural laws (natural necessity) (Linnemann 2020, pp. 1–2). Fine (2002), for example, argues that metaphysical necessity is 'the sense of necessity that obtains in virtue of the identity of things' (Fine 2002, p. 254), and that not all natural necessities are metaphysical necessities. For example, 'light has a maximum velocity' is at most naturally necessary but not metaphysically necessary. Likewise, even though it is arguably naturally necessary that mass attracts mass with an inverse square law, this does not seem to render it metaphysically necessary (one would think that an inverse cube law for the attraction between masses is as such metaphysically possible). It might be objected that if an inverse cube law (rather than inverse square law) holds, we would not be dealing with 'mass' but with something else (e.g. 'schmass'). However, on the one hand, it is a natural necessity that there is no schmass, on the other hand, the objector is assuming the existence of schmass as a metaphysical possibility. This goes to underscore Fine's point that not all natural necessities are metaphysical necessities (Linnemann 2020).

Lange (2009, p. 45) contrasts the putative necessity of the laws of nature with other putative species of necessity, such as:

1. (Narrowly) logical necessity (e.g. either all emeralds are green or some emerald is not green)
2. Conceptual necessity (all sisters are female)
3. Mathematical necessity (there is no largest prime number)
4. Metaphysical necessity (water is H_2O)
5. Moral necessity (one ought not torture babies to death for fun)
6. Broadly logical necessity (as possessed by a truth in any of these categories)

Lange (2009, pp. xi–xii) notes that, while the laws of nature have traditionally been thought to possess a distinctive species of necessity (dubbed 'natural' necessity) an exception to which is (naturally) impossible, yet many have also regarded the laws of nature to be contingent; unlike the broadly logical truths listed above, the laws of nature could have been different from the way they actually are. Essentialists disagree; they characterize laws as possessing the same strong variety of necessity as broadly logical truths do (Ellis 2001). While one can imagine these laws to be false (e.g. one can imagine a different universe in which gravity does not exist), Bird (2007, p. 207) replies by claiming that

> imagination is a poor guide to the modality of laws, if one supposes that the power of imagination evolved to allow us to think about the sort of possibilities—concrete, perceptible states of affairs that we might actually come across (predators in the bushes)—rather than esoteric possibilities (if they really were such) we would never experience such as a world with different laws. It can be shown how Kripke's explanation for the illusion of contingency can be extended to laws.

While some have thought that the laws of nature break down at the Big Bang, physicist Paul Davies explains that there are still other versions of the laws of nature which hold at the Big Bang. Davies (2013) explains:

> Physicists have discovered that the laws of physics familiar in the laboratory may change form at very high temperatures, such as the ultra-hot environment of the Big Bang. As the universe expanded and cooled, various 'effective laws' crystallized out from the fundamental underlying laws, sometimes manifesting random features. It is the high-temperature versions of the laws, not their ordinary, lab-tested descendants, that are regarded as truly fundamental.

Nevertheless, there could still be alternative universes in which different properties and different laws of nature exist, whereas the laws of logic exist in all possible universe. Lange (2009, p. 77) argues that it is in this sense in which the contingency aspect of the laws of nature is to be understood, noting that the range of counterfactual suppositions under which the laws of nature must all be preserved, for the set of laws to qualify as stable, is narrower than the range of counterfactual suppositions under which the broadly logical truths must all be preserved, for the set of broadly logical truths to qualify as stable.

According to the dispositionalist view, the necessity aspect of the laws of nature is grounded in dispositional properties understood as natural clusters of powers (Mumford 2004, pp. 161, 170). On the dispositionalist view, apples regularly fall towards the earth because both apples and the earth have mass understood as a dispositional property, and the resulting regularities can be described by the abstract equations we call the laws of nature (Dumsday 2019, pp. 10–11). Dorato and Esfeld (2014) argue that the view that laws are grounded in properties (global properties rather than 'intrinsic' or local properties, in view of quantum entanglement) make intelligible how laws can 'govern' the behaviour of objects. This is the decisive advantage of dispositionalism over primitivism (the view that laws are primitive; see Maudlin 2007). According to the essentialist view, the causally necessary connections are explications of the essential properties of the natural kinds (Ellis 2001). Essentialists agree that some properties are essentially dispositional, but they argue that others (e.g. spatiotemporal properties) are not (Choi and Fara 2018; see further, Section 3.8.3).

Dumsday (2019, p. 119) has defended dispositionalism against Lange's attempt to reduce dispositions to subjunctive facts, by situating dispositionalism within robust natural-kind essentialism. 'Although the dispositions are real and irreducible (hence preserving dispositionalism), they are not ungrounded, but instead are rooted in the kind. Consequently, dispositions cannot be reducible to primitive subjunctives. And the kind in its turn is not reducible to a primitive subjunctive fact, as its explanatory role goes beyond that of such a fact' (p. 120). 'A primitive subjunctive fact is ordered to a possible future state of affairs, and cannot, in and of itself, explain the present instantiation of a categorical property like shape or size. By contrast, the kind-essence, as traditionally conceived, does exactly that' (ibid.; noting on p. 122 that kind-talk is utterly ubiquitous across all the natural sciences and the efforts of many physicists devoted to the classification of apparently fundamental types of particle in terms of kinds).

It has been objected that there are some laws of nature that could not be explained in terms of causal powers. For example, the law of conservation of energy indicates that interactions are constrained by the requirement of preserving the mass-energy, but that constraint does not seem to be the manifestation of a disposition (Chalmers 1999, pp. 12–13). Mumford (2004, p. 199) replies that what have been labelled as 'laws of nature' are actually a very diverse bunch: 'Some causal laws might be best explained in terms of causal powers but others might be better explained in terms of metaphysical connections between properties and others might merely describe the structure of space–time or the nature and limit of energy.' I shall argue in Chap. 3 that the law of conservation of energy should be explained in terms of the Causal Principle.

Mumford (2004) has gone further and argued that, given that the concept of a governing law of nature is no longer plausible, 'law of nature' should be discarded. Bird (2007, pp. 189–190) disagrees by appealing to the widespread usage and function of the term in science which indicate that the governing role is not essential to the definition. Bird defines a law of nature as follows: (L) The laws of a domain are the fundamental, general explanatory relationships between kinds, quantities, and qualities of that domain, that supervene upon the essential natures of those things (p. 201).[13]

Dumsday (2019, chapter 2) has replied to Mumford that at least some dispositions have CP clauses incorporating uninstantiated universals (which CP clauses help to delimit the range of manifestations of those dispositions), which imply that the laws of nature exist. Dumsday claims that a Platonist may argue that, while the disposition instances do the causal work, the Platonic universals set the rules by which they operate, and the laws of nature can be understood as relations between universals which govern the causal/dispositional roles that properties play as a matter of metaphysical necessity (Dumsday 2019, chapter 2). However, the notion of 'setting the rules' and 'govern' is misleading, since abstract objects do not have causal power to set or govern anything. As noted above, abstract objects such as the equations of physics are merely descriptive of behaviour; thus, there must be something concrete that 'makes it the case that the world actually operates in accordance with the equations, rather than some other equations or no equations at all' (Feser 2013, pp. 45–46).

Traditionally, this concrete entity is God. Bird (2007, pp. 189) notes the theologico-legal origins of the concept of the laws of nature as the decrees of God. Historically, the use of the term 'law of nature' is related to legislation by an intelligent deity (Brooke 1991, p. 26). Mumford (2004, pp. 202–203) objects to the use of this terminology, arguing that, while moral and legal laws are issued to conscious agents who can understanding them and decide whether to obey them or not, physical entities cannot understand and choose, and they could not have behaved other than the way they do because their behaviour are tied necessarily to their properties understood to be clusters of causal powers. He denies the existence of laws imposed on any things, which they then govern.

In reply, it can still be argued that the regularities indicate a Governor (God) who determined the properties of physical entities to be such that they move regularly according to equations in a law-like manner noted by Bird (see Chaps. 4 and 7). This conclusion does not require the views that (1) God has created a perfect world fine-tuned to his ends, (2) there is a universal and complete order in nature, and/or (3) what happens in nature can be described in universal and exceptionless laws.[14] On the contrary, the new groundbreaking view of nature as not universally law-governed (see above) fits well with the claim that, while God determined the properties of physical entities, He also judiciously intervenes in nature at key points to direct its ends (Gingerich 2006).

In any case, one still needs to ask where these 'laws of nature' come from. One might think that the 'laws of nature' express abstract relations between universals which physical things somehow 'participate in' (something like the way every tree participates in the Form of Tree; see Armstrong 1983). However, we would still need to know how it comes to be that there is a physical world that 'participates in' the laws in the first place, why it participates in these laws rather than others, and so on, and this indicates that the laws of nature cannot be ultimate explanations (Feser 2017, pp. 279–280). As I argue in the rest of this book, the answers to these questions are found in an intelligent First Cause.

In summary, fundamental physics does not provide a complete description of reality. It does not exclude efficient causation and causal properties which operate at a more fundamental level as the ground of the regularities described by fundamental physics. The latter point is further supported by the argument for the Causal Principle (see Chap. 3).

2.4 Considerations of Quantum Indeterminancy

The Causal Principle has been rejected in recent years by some philosophers due to considerations from quantum-mechanical indeterminacy (Grünbaum 2009, p. 15). However, others have responded that quantum particles emerge from the quantum vacuum which is not non-being, but something with vacuum fields (quantum particles are manifestations of fields) and which can be acted on by the relevant laws of nature (Bussey 2013, p. 33). Given that the pre-existent quantum fields and the capacities to be acted on by the relevant laws of nature are the necessary conditions for bringing about these quantum events, it is not the case that these quantum events are uncaused (see the definition of uncaused in Sect. 2.2).

It has sometimes been thought that Heisenberg's uncertainty principle violates the Causal Principle. This is a misunderstanding. The 'uncertainty' in question does not imply it is possible that energy comes from absolute nothing; it just means that the pre-existing energy (i.e. the vacuum energy which is already present) can (unpredictably) have a very high value in a very short period of time, such that the uncertainty of the energy measurement can be very large.

While some scientists have proposed theories according to which the universe began to exist from 'nothing' (e.g. Vilenkin 2006; Krauss 2012), cosmologist George Ellis objects that the efforts by these scientists cannot truly 'solve' the issue of creation, 'for they rely on some structures or other (e.g. the elaborate framework of quantum field theory and much of the standard model of particle physics) pre-existing the origin of the universe, and hence themselves requiring explanation' (Ellis 2007, section 2.7). Ellis' objection indicates that what these scientists mean by 'nothing' cannot be the absence of anything; rather, there needs to be something that can behave according to physics in order for their physical theories to work.

Moreover, it has already been explained in Chap. 1 that, in view of the importance of philosophical considerations for evaluating scientific theories, cosmologists should not merely construct models of the universe without considering the philosophical arguments against certain models. If what these scientists mean by 'nothing' is truly the absence of anything, then their theory would be refuted by philosophical arguments for the Causal Principle (see Chap. 3) which they have not successfully rebutted.

Even if it is the case that the negative gravitational energy of our universe exactly cancels the positive energy represented by matter so that the total energy of the universe is zero, as suggested by the Zero Energy Universe Theory (see Chap. 5), this does not imply that the positive and negative energy arose uncaused from zero energy. One can still ask what is the efficient cause which made the positive and negative energy to be the way they are. To conclude otherwise is to commit the logical fallacy of thinking that 'net zero imply no cause'. (This logical fallacy may be illustrated using the following analogy: the fact that my company's total expenses cancel the total revenue, such that the net profit is zero, does not imply that the expenses and revenue occurred without an efficient cause. We still need to ask what made the expenses and revenue to be the way they are.)

As for the radioactive disintegration of atomic nuclei, even if events such as the decay of a given atom of 235U at this instant rather than (say) two weeks from now do not have a sufficient cause, there is strong justification for maintaining that the phenomena (the decay and statistics they exhibit) themselves have underlying proportionate causal explanations, for they exhibit regularities that strongly indicate the existence of more fundamental ordered causes (Stoeger 2001, p. 87). These fundamental ordered causes would be entities that are causally antecedent to the radioactive disintegration of atomic nuclei. Physicist Peter Bussey (2013, p. 20) notes that 'beta-decay is due to the so-called "weak nuclear force", in whose absence the decay would not occur. So the cause of the new nuclear state is the weak force acting on the previous nuclear state.'

Additionally, many different interpretations of quantum physics exist, and some of them, such as Everett's Many Worlds interpretation and Bohm's pilot-wave model, are perfectly deterministic. A number of scientists and philosophers have argued that Bohm's theory is superior to the indeterministic Copenhagen interpretation (Towler 2009a, b; Goldstein 2013; I discuss this in Loke 2017, chapter 5), and that it can explain Heisenberg's uncertainty principle (Bricmont 2017, section 5.1.8). Contrary to popular opinion, physicist John Bell has not demonstrated the impossibility of hidden variables, but only the (apparent) inevitability of non-locality of quantum physics;[15] Bell himself defended Bohm's hidden variable theory (Bell 1987). Likewise, Alain Aspect (2002), the noted experimenter of quantum entanglement, agrees that his experiment does not violate determinism but only the locality condition. While it has been objected that Bohm's theory is incompatible with theory of relativity (Lewis 2016, p. 180), others have replied that, if Bohmian mechanics indeed cannot be made relativistic, it seems likely that quantum mechanics can't either (Dürr et al. 2014; Maudlin [2018] defends Bohmian mechanics by arguing that fundamental Lorentz invariance can be violated, and that observational Lorentz invariance can be explained by appealing to quantum equilibrium). With regard to quantum field theory, Bricmont (2017, p. 170) proposes Bohm-like quantum field theories in which dynamics are defined

> for the fields rather than for the particles, and the guidance equation would apply to the dynamics of field configurations. … One can also propose other Bohm-like quantum field theories, including theories of particles and their pair creation … all the predictions of the usual quantum field theories are also obtained in those Bohmian-type models and, to the extent that those models are rather ill-defined mathematically, the same thing is true for ordinary quantum field theories, which is not the case for non-relativistic quantum mechanics or the corresponding de Broglie–Bohm theory for particles.

Now Bohm's theory is not the only possible deterministic quantum theory; other deterministic quantum theories that are better than Bohm's (as well as better than the indeterministic Copenhagen interpretation) might well be discovered in the future. The inability to predict the appearance of the quantum particles in quantum vacuum may be due to our epistemological limitation and the incompleteness of current quantum physics. As Einstein [1949, p. 666] remarks, 'I am, in fact, firmly convinced that the essentially statistical character of contemporary quantum theory is solely to be ascribed to the fact that this (theory) operates with an incomplete description of physical systems.' Physicist John Wheeler notes that our current understanding of quantum mechanics is provisional, and that it is plausible to think that some deeper theory, waiting to be discovered, would explain in a clear and rational way all the oddities of the quantum world, and would, in turn, explain the apparent fuzziness in the quantum classical boundary (Ford 2011, p. 263). Given that our current understanding of the quantum world is provisional, it is false to claim that quantum physics has shown that events can begin to exist without necessary or sufficient conditions.

In conclusion, it has been argued that no compelling scientific evidence against the Causal Principle has been offered. In the next chapter, I shall discuss a number of arguments for the Causal Principle.

Notes

1. Something can have a beginning even if its temporal extension is an actual infinite (e.g. if something begins to exist in the year 2020 and exists endlessly in the later-than direction on the static theory of time). However, if something is finite in temporal extension and has temporal edges, it would have a beginning.
2. Here, part of a thing refers to a temporal part. See perdurantism, below.
3. I thank Oners for raising this objection and for the discussion below.
4. Strictly speaking, the purported evidence for the B theory does not prove that the block never comes to be; see Chap. 6.
5. Proponents of probabilistic causation acknowledge that there are sufficient causes and necessary conditions, and they regard sufficient causes as constituting a limiting case of probabilistic causes, but they deny that this limiting case includes all bona fide cause–effect relations (Williamson 2009, p. 192). It should be noted that a cause can be causally sufficient but not causally necessary for an effect.
6. Weaver (2019, chapter 7) argues that there are no plausible metaphysical theories of omissions understood as absences that are causal relata, and that virtually all supposed cases of negative causation can be faithfully/accurately re-described without omissions/absences.
7. Hence, by uncaused First Cause, I mean the First Cause of change, and that this First Cause is not something that is brought into existence. However, such a First Cause might be something that is sustained in existence, and thus is caused in the sense of having a sustaining cause. See further, Chaps. 6 and 8.
8. Weaver goes on to explain that he agrees with David Lewis (1986) that causation should be understood in terms of causal dependence, but disagrees with Lewis' additional step of reducing causal dependence to counterfactual dependence. He argues on page 261 that the heart of the causal interpretation of General Theory of Relativity (GTR) is not a relation that is reducible to counterfactual dependence, probabilistic dependence, the transfer of energy or momentum, or some other reductive surrogate relation or process.

9. I thank Michael Dodds for this point.
10. Curiel (2019) notes that 'the Second Law of thermodynamics has long been connected to the seeming asymmetry of the arrow of time, that time seems to flow, so to speak, in only one direction for all systems'.
11. See the discussion on dispositionalism and essentialism below.
12. Collins (2009, p. 270) notes that the laws of physics are not strictly speaking time-reversal invariant—since time-reversal symmetry is broken in weak interactions, notably the decay of neutral kaons.
13. Cf. The *Oxford Dictionary of Physics*' definition of a law in science as 'a descriptive principle of nature that holds in all circumstances covered by the wording of the law' (Issacs 2000, p. 260).
14. Cartwright (2016) states that since at least the Scientific Revolution three theses have marched hand in hand.
15. Tim Mawson points out to me that Bell's results do not even show that non-locality is violated; this 'loophole' is sometimes discussed under the name 'Superdeterminism'.

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