Preprint: To appear in The Routledge Companion to the Philosophy of Time, edited by Nina Emery

The Direction of Time

Alison Fernandes

Abstract:
Time seems to be directed from the past to the future. Based on this appearance, some argue that time has an 'intrinsic' or primitive direction—a direction of time in and of itself. Others argue that time has, at best, a 'reduced' direction—a direction that is due to the arrangement or orientation of other phenomena in time. Much of the debate over time's direction concerns whether an intrinsic direction is required to explain temporal asymmetries in the world and our experience.

---

1. Introduction

Time seems to have a direction, or an 'arrow', oriented from the past to the future. This apparent direction is reflected in our talk of what '*has'* happened as distinct from what '*will'* happen, in our ordering of events using '*before'* and '*after'* and in our talk of processes and other phenomena that occur in time. Plants 'grow' when they increase in size in the forwards, but not backwards, direction of time. This apparent direction of time is distinct from other apparent features of time such as time's flow or the apparent openness of the future and fixity of the past—features that are more often the subject of metaphysical debate. These features, however, presuppose that time has a direction—making settling the issue of the direction of time important groundwork for these debates.

What sense can we make of an apparent direction of time? One issue concerns whether time has an *intrinsic* or *primitive* direction—a direction that time has in and of time itself, independently of other things. A second issue concerns whether time has a *reduced* direction—a direction that depends on the orientation or arrangement of other phenomena in time. For example, one might argue that the direction of time is just the temporal direction in which causal relations lie, such that the direction from cause to effect determines the direction from past to future. Exactly what it is to 'reduce' the direction of time is a subtle matter (Section 4). While often the debate is framed as whether the direction of time is primitive *or* reduced (Loewer 2012, see also North 2011), these are two distinct issues. One may hold that time has a reduced direction but be agnostic over whether it has an intrinsic direction. One may hold that time has both a reduced and an intrinsic direction. Or one might deny that time has a direction in either sense. Depending on one's definition of reduction, these are not just logical possibilities, but positions that philosophers have held. For an analogy, consider different attitudes one could take to the existence of atoms. Even if we accept the existence of atoms as non-fundamental entities, there is still a debate to be had over whether there are, in addition, fundamental particles that also warrant the label 'atom'. One might also deny the existence of atoms in either sense. To reflect this nuance, we'll discuss arguments for an intrinsic direction of time separately from those for a reduced direction.

A related set of issues concerns *what determines* whether time has a direction. Most take time's directedness to partly turn on what is required to explain temporal asymmetries in the world and our experience. But there remains disagreement. For some, whether time has an intrinsic direction is determined by whether the fundamental laws (the laws of final fundamental physics) distinguish between two directions in time (Horwich 1987; Arntzenius 2004; North 2008, 2011; Arntzenius and Greaves 2009). For others, we need to look to the *preconditions* for any fundamental laws (Maudlin 2007). For others, time's intrinsic character is determined by our common-sense experience of time (Zimmerman 2007). Differences in methodology account for some of the entrenched disagreements in the debate.

In Section 2, I'll consider arguments in favour of time having an intrinsic direction that are independent of the form of fundamental physical laws. In Section 3, I'll consider arguments for an intrinsic direction that depend on the form of fundamental physical laws. In Section 4 I turn to arguments over whether time has a reduced direction.

Before I begin, some disclaimers. First, while I will talk of 'past', 'present' and 'future', these are standardly to be read as meaning 'before', 'simultaneous with' or 'after' a particular time. Such talk does not presuppose a so-called *A-theory* of time in which past, present and future are objectively different regions of time. Second, I'll stay as neutral as possible regarding substantivalism versus relationalism: roughly, whether spacetime is best modelled as a container in which things happen or as relations between happenings. Third, in order not to presuppose too much physics, I will mostly only assume Newtonian mechanics rather than General Relativity. See Earman (1974), Malament (2004), Maudlin (2007: 115−7) and Callender (2017: Ch. 2) for relevant discussions of General Relativity.

2. Preliminary Arguments for an Intrinsic Direction of Time

Some believe that time has an intrinsic direction and their reasons for thinking so are broadly that this view best accommodates our intuitive or 'common-sense' picture of the world. Those defending so-called *A-theories* of time typically fall into this camp (Zimmerman 2007; Ingram, this volume)—see Horwich (1987: Ch. 2) and Price (1996: Ch. 1) for critical discussion. According to A-theorists, the past, present and future are objectively distinct regions of time, whose locations change over time. A-theories require time to have an intrinsic direction. This direction is both the direction in which the present moves and the direction that points from the past region to the future region. Most opponents of A-theorists are B-theorists, who believe that the past, present and future are merely locations *relative* to a particular point in time, in the same way that 'here' is not an objectively distinct place, but a location relative to a particular point in space.

But one may deny A-theory and still take time to have an intrinsic direction. Maudlin (2007: Ch. 4; see also Earman 1974) denies that there is an objective present. But he defends the claim that there is a 'passage of time', 'an intrinsic asymmetry in the temporal structure of the world' (2007: 108) that underwrites 'claims about one state 'coming out of ' or 'being produced from' another' (ibid.: 110). Maudlin's view is sometimes labelled as a 'B-theory' of time (Maudlin 2007: 126, fn. 11; Farr 2020a), as distinct from a 'C-theory', which denies both an objective present and an intrinsic direction of time. But often 'B-theory' is used to label *all* those views that deny an objective present. Regardless, Maudlin's view is unusual. Most who deny an objective present also deny that time has an intrinsic direction.

Many of the arguments in favour of time having an intrinsic direction take the form of identifying some phenomenon in our common-sense experience of the world that we associate with the direction of time and arguing that the phenomenon would not be possible without an intrinsic direction of time. Examples include arguments from our experience of the 'flow' of time (Maudlin 2007: 135; Zimmerman 2007—see Baron et al (2015) for discussion), arguments from our use of tensed language (Prior 1959), arguments from the appearance of change (Maudlin 2007: 127), arguments from the direction of causation (Mackie 1974: 225−6; Maudlin 2007: 176−7) and arguments from temporal asymmetries in our attitudes, such as the way we value past and future events differently (Prior 1959; Maudlin 2007: 135; Zimmerman 2007).

In response, sometimes the phenomenon is called into question (Hoerl 2014). But the more common response is to accept the phenomenon, but to deny that it indicates time has an intrinsic direction because it can be explained without that assumption. Sometimes these arguments proceed on a case-by-case basis. Callender (2017: Ch. 2) argues that we value past and future events differently because of causal facts—not because of an intrinsic direction of time. But a general argument can be given for why an intrinsic direction of time is not needed to explain *any* temporal asymmetry. The following 'epistemic argument' is a reconstruction of arguments by Williams (1951: 468−9), Price (1992a: 513; 2007: 264; 1996: 14−15) and Loewer (2012: 133−5).

Assume that our world has an intrinsic direction of time. Then, consider a world that is very similar, except that this intrinsic direction of time is reversed. In this world, there is still a time when the universe is compressed in a 'big bang' like state, still a time when the universe is much larger and contains a planet with a range of life species including humanoid bipeds. The differences are that these events occur in the opposite temporal order from similar events at our world. The 'big bang' like state is this world's final state, for example, and involves the universe collapsing into a smaller state. It seems that this time-reversed world would contain creatures like us with similar memories, plans, and anticipations. The only difference is that while the time-reversed creatures remember the same kind of events that we do, such as their childhoods, these aren't memories of the past but of the *future*. Similarly, they will anticipate and form intentions about the *past* and not the future. They will think of the past as open and the future as fixed. Similarly for other phenomena: babies will grow and ice cubes will melt in the past direction. All the phenomena we associate with the direction of time will be reversed with respect to the intrinsic direction of time at this world. While these creatures will talk about time having a direction and its being manifest in these phenomena, these creatures will be radically mistaken about time's intrinsic direction. But then, how do we know we're not in the position of these creatures? With what right do we assume that the phenomena we take the direction of time to be manifest in actually align with an intrinsic direction of time? If we allow for this skeptical possibility, it seems we can't argue from temporal asymmetries in our experience or the world to time's intrinsic directedness.

One might respond that it is impossible to reverse an intrinsic direction of time at a world while leaving its events qualitatively unchanged. Isn't it obvious that there is only one way that events like ours could be temporally ordered? But there is an argument from the form of fundamental physical laws that such reversals are possible. To consider this argument, we'll need the concept of a law being 'time-reversal symmetric' or 'time-reversal invariant', meaning that it takes the same *form* in either direction and has no preferred orientation. If the fundamental laws of a world are all time-reversal symmetric, the time-reversed sequence of a lawful evolution is also in accord with the fundamental laws. Metaphorically, if one were to play a movie of the world in reverse, its behaviour would still be in accord with the laws. Exactly how to formulate time-reversal symmetry is controversial (Albert 2000: 5−21; Arntzenius 2004; Malament 2004; North 2008, 2011; Arntzenius and Greaves 2009; Callender 2021). But the following are typically taken to be paradigms of time-reversal symmetric laws: the laws of Newtonian mechanics, the laws of General Relativity and the laws of the evolution of the wavefunction in quantum mechanics described by the Schrödinger equation. If the fundamental laws of our world are time-reversal symmetric, and these laws demarcate the space of physical possibilities, then the time-reversed world is *physically possible*.

Arguably, we don't yet know whether the laws of our world are time-reversal symmetric (see Section 3). For now, say we accept the epistemic possibility of our laws being time-reversal symmetric. After all, we used to think our laws were time-reversal symmetric and many candidates for fundamental physical laws are so. If so, the epistemic argument still holds—we have no epistemic guarantee that the phenomena that we take the direction of time to be manifest in align with an intrinsic direction of time. Moreover, the arguments in favour of time's intrinsic directedness turn out to depend on the form of the fundamental laws—contrary to appearances.

In response to the epistemic argument, Maudlin (2007: 121−3) claims that we have no reason to believe that creatures in the time-reversed world would have any kind of experience at all. More generally, he argues that the physical processes in the time-reversed world are entirely unlike the physical processes that take place in our world. So, there are no issues regarding indistinguishability. One of Maudlin's arguments relates to what counts as time-reversal symmetry. Maudlin notes (2007: 118−9) that we cannot simply reverse the *order* of a series of instantaneous states to have a time-reversed possibility. We must apply a time-reversal operator to the instantaneous states themselves. We must reverse the velocities in which particles are moving, for example. Since instantaneous states have a direction, Maudlin argues, there must be an intrinsic direction of time with respect to which they are oriented. More generally, Maudlin takes change, processes or happenings in any reasonable sense to require an intrinsic direction of time (ibid.: 128). We need an intrinsic direction of time to distinguish between processes as simple as movement to the left and movement to the right (ibid: 110). There is a second way in which Maudlin rejects time-reversal indistinguishability. He argues that having a world governed by dynamical laws requires an intrinsic direction of time, since these laws must 'produce' later states from earlier states in accord with the direction of time (ibid.: 174−5). If Maudlin is right, then merely the dynamical character of laws or the directedness of processes gives us reason to posit an intrinsic direction of time.

Worries, remain, however. First, even if we accept that processes require *a* direction of time, Maudlin hasn't yet explained how that direction is manifest. Answering the epistemic argument requires not just arguing that *an* intrinsic arrow is required, but that an intrinsic arrow *in a particular direction* is required. The above arguments, on which Maudlin puts the most weight, don't answer that concern. I consider a third argument by Maudlin in Section 4. Second, Maudlin's response requires that conscious states be treated differently from physical states (Price 2011). In the case of physical states, neither the productive character of laws nor the temporal directedness of instantaneous states prevents a 'quasi' temporal reverse of these states being possible. If an asteroid moving from the left to the right is possible, then so is an asteroid moving from the right to the left. Yet in the case of consciousness, the direction of time is supposed to prevent the 'quasi' temporal reverse being possible—such as creatures who remember the future. What this implies is that consciousness can detect a direction of time in a way that regular physical instruments cannot.

Putting these worries aside, Maudlin's response leads to something of a stalemate. The uncontroversial phenomena he appeals to, such as the distinction between motion to the left and motion to the right, or the fact that we explain the future using the past but not vice versa, don't straightforwardly imply an intrinsic direction of time. A reduced or apparent direction of time may be able to explain those same phenomena (Section 4)—tying Maudlin's acceptance of an intrinsic direction to his rejection of a reduced direction. Insofar Maudlin appeals to phenomena that require a primitive direction of time as a matter of definition, opponents can simply deny the phenomenon obtains (such as that laws 'produce' later states), perhaps while accepting a nearby phenomenon that does not require a primitive direction of time (such as that laws 'constrain' later states). Maudlin is aware of the stalemate. His motivations for accepting an intrinsic direction of time are driven by his preference for a view that is 'much closer to the intuitive picture of the world' (2007: 182). But not everyone accepts that common-sense should be a guide to metaphysics. Moreover, as Maudlin is aware (ibid.: Ch. 6), such a principle would still need to be balanced against other criteria, including fit with science (Paul 2014).

3. Arguments for an Intrinsic Direction of Time Based in the Form of Physical Laws

A distinct argument for an intrinsic direction of time is that such a direction is evidenced by the form of fundamental physical dynamical laws—namely that they are 'time-reversal *asymmetric*'. The claim is not that the direction of time reduces to a direction in the laws, but that a direction in the laws indicates an intrinsic direction in time. There is some evidence that our fundamental dynamical laws are time-reversal asymmetric. There are observed violations of CP (charge, parity) symmetry in the decay of particles called neutral k mesons or 'kaons'. Given that we take CPT (the combination of charge conjugation, parity and time-reversal) symmetry to be preserved, the violations of CP symmetry indicate violations of temporal symmetry—suggesting that the fundamental laws governing such decays are time-reversal *asymmetric*. There are also candidate theories of fundamental physics whose laws are time-reversal asymmetric, the most well-known being the 'GRW' version of quantum mechanics (Ghirardi, Rimini, & Weber 1986).

Before we consider the philosophical argument, a few notes about the physics. First, a temporal asymmetry in physical phenomena does not straightforwardly imply time-reversal asymmetry in the laws. Another possible source of temporal asymmetries is boundary conditions, typically special initial conditions. This is the situation in classical statistical mechanics, where time-reversal symmetric laws and special initial conditions imply temporal asymmetric behaviour. Whether the observed CP violations indicate a temporal asymmetry in the laws ultimately depends on the final form taken by fundamental physics. Second, the implications of CP violations depend on how time-reversal symmetry is formulated. If time-reversal requires CP reversal, there is no violation of temporal symmetry. See Arntzenius and Greaves (2009) and Wallace (2014) for discussion. Third, some candidate time-reversal asymmetric laws, including those of GRW, are taken by their proponents to be at best 'effective', that is, not fundamental. Putting these points together, while we should take seriously the possibility of our fundamental laws being time-reversal asymmetric, whether they are remains an open question—especially since key issues in the foundations of physics remain unsettled.

Assuming for the moment that the fundamental dynamical laws are time-reversal asymmetric, what would this imply about the direction of time? Some argue that even time-reversal asymmetric fundamental laws would not indicate that time itself is directed (Price 2011; Farr 2020b). A direction of time isn't needed to 'tell' the laws which way to go. If so, the issue over time-reversal symmetry is something of a red herring—time lacks a direction, whether or not the fundamental dynamical laws are time-reversal symmetric. Others argue that there must some kind of match between time and laws, such that a direction of laws indicates an intrinsic direction of time. We might need an intrinsic direction to state time-reversal asymmetric laws (North 2008: 202−4), to state the theory in a co-ordinate independent way (Arntzenius 2004; Arntzenius and Greaves 2009) or to explain why the relevant law-governed processes occur in one direction and not the other (Horwich 1987: 41−2).

But there are worries. First, it is unclear why many of these roles couldn't be played by a reduced direction of time—a direction that may even be in part due to the asymmetric laws themselves. For example, it seems that it's the temporally asymmetric laws that explain why law-governed processes occur in one direction and not the other. Second, temporal asymmetries in kaon decay rates seem largely irrelevant to explaining the temporal asymmetries in which we take the direction of time to be manifest—see Maudlin (2007: 135−7) and Wallace (2014). If so, perhaps the asymmetry in time indicated by CP violations isn't something that deserves to be called a 'direction' of time. More cautiously, it seems that even if one accepts or remains agnostic about an intrinsic direction of time indicated by the form of fundamental physical laws, there is still a project of explaining a further sense of the direction of time—one closely tied to temporal asymmetries we more directly experience.

4. A Reduced Direction of Time

A *reduced* direction of time is, in the first instance, a direction of time that depends on the arrangement or orientation of other phenomena. 'Reductionism' is sometimes used narrowly (Price 1996, 2002, 2011; Maudlin 2007) to indicate views in which some phenomenon's orientation or arrangement either *constitutes* the direction of time (metaphysical reduction), is what we really mean or ought to mean by 'the direction of time' (conceptual reduction) or explains the *truth*, *use* or *apparent success* of our talk about the direction of time (explanatory reduction). For example, one might argue that the direction of entropy increase constitutes the direction of time, because the direction of entropy increase explains various phenomena we associate with the direction of time. But 'reductionism' is also used broadly (Loewer 2012: 117) to indicate any view that explains real or apparent temporal asymmetries without presupposing an intrinsic direction of time. Many of those typically identified as reductionists, including Lewis (1979), Horwich (1987), Albert (2000, 2015), Loewer (2012), Callender (2017) and Rovelli (2018), don't claim what the direction of time reduces to and some (Horwich: 49−51; Price 1996, 2002, 2011; Callender 2017: Ch. 13) have principled reasons for rejecting reductionism in the narrow sense. For completeness, I adopt the broad reading here.

Following Reichenbach (1956), we might take reductionists (in the broad sense) to be committed to explaining key phenomena that we associate with the direction of time by a) specifying a more precise sense of the phenomena, and b) explaining that precise phenomenon without presupposing an intrinsic direction of time. These key phenomena are typically temporal asymmetries—asymmetries in how things are oriented or arranged in time—that we associate with the direction of time, such as temporal asymmetries in records and causation. According to this way of setting up the debate, there is not one thing 'the direction of time'. Instead, there are various temporal asymmetries, imperfectly understood, and the question is whether these phenomena are best explained by an intrinsic direction of time or something else.

The key temporal asymmetries that reductionists typically seek to explain include the Second Law of thermodynamics (roughly, the fact that the entropy of isolated systems at non-maximal entropy increases towards the future and not the past), the record asymmetry (the fact that we have records of the past and not the future) and the temporal asymmetry of causation (the fact that causes come before their effects). Other temporal asymmetries discussed in philosophy of physics include those of radiation, electrodynamics and cosmology (Price 1996; Frisch 2014; Callender 2021). Other relevant temporal asymmetries are typically higher-level or apparent and include the apparent flow of time, the apparent fixity of the past and openness of the future, and asymmetries in values and emotions. Most reductionists aim to give recognizably scientific explanations of these asymmetries, broadly modelled off explanations given in statistical mechanics.

In the tradition of classical statistical mechanics following Boltzmann, one explains the rise in entropy of the universe and of isolated subsystems using temporally symmetric laws, a temporally symmetric probability postulate and a constraint on the initial state of the universe. The most common constraint has come to be known as the 'Past Hypothesis' (Albert 2000), the claim that the universe started out in the particular low-entropy macrostate that it did. From these posits, one can derive that the universe is overwhelmingly likely to increase in entropy towards the future and not the past, and that the entropy of isolated subsystems at non-maximal entropy is overwhelmingly likely to increase towards the future and not the past—see Albert (2000), North (2011), Loewer (2012) and Shenker and Hemmo (this volume) for details.

Most reductionists take the records and causal asymmetry to be key phenomena that must be explained. They also take these asymmetries to be closely related—either one directly explains the other (Albert 2000, 2015; Loewer 2012) or they are both manifestations of the same underlying asymmetry (Reichenbach 1956). We'll start with the record asymmetry. The record asymmetry is typically taken to be the fact that there are localised physical states in the present that reliably indicate past states, but not future states, relatively independently of other states. For example, there might be a newspaper report that reliably indicates the weather one year ago, without one needing to know anything about today's weather. But we don't have anything like newspaper reports that reliably indicate the weather one year in the future. At best we can infer future weather using much more extensive knowledge of past weather patterns and today's weather. All kinds of physical states such as photographs, letters, digital recordings as well as our memories are taken to be examples of records. Assuming this is so, from an asymmetry of records, we can recover the fact that we remember the past and not the future, which seems to be a significant contributor to our sense that the past is fixed and the future is open, and so to our sense that time has a direction.

Various attempts have been made to explain the record asymmetry. Some rely closely on entropy or the Past Hypothesis (Reichenbach 1956: Ch. 16; Albert 2000; Loewer 2012), such that the low-entropy past or the entropic increase of the universe and isolated subsystems imply that there are reliable ways of inferring towards the past using local states that aren't available toward the future. Others focus more (or additionally) on patterns in macroprobabilistic structure (Reichenbach 1956, Chs. 17−21; Horwich 1987; Stradis 2021). Presumably, asymmetries in macroprobabilistic structure will need to be traced back to more basic entropic asymmetries—see Fernandes (2023: Ch. 5). Different accounts of the record asymmetry rely on different precise definitions of what records are and some also differ on whether the record asymmetry is strict. See, for example, Fernandes (2022) for a critical comparison of Albert's and Reichenbach's approaches. Ultimately, there are likely to be several different ways in which temporal asymmetries in physical states facilitate our reasoning towards the past in ways that are different (or different in degree from) our reasoning towards the future.

The temporal asymmetry of causation is the fact that causes come before their effects at our world. Causation's temporal asymmetry also seems closely tied to our sense that the past is fixed and the future is open, that the past determines or produces the future and that we control the future and not the past (Ismael 2012)—and so is presumably a significant contributor to our sense that time has a direction. Many further temporal asymmetries are explained using the temporal asymmetry of causation—including those in higher-level sciences and those relating to emotions and attitudes (see, for example, Callender 2017: Ch. 12). The temporal asymmetry of causation is also typically taken to be related to a temporal asymmetry of counterfactuals.

There are three major programs that attempt to explain the temporal asymmetry of causation in broadly scientific terms: statistical-mechanical accounts (Albert 2000, 2015; Loewer 2007, 2012), agency accounts (Price 1992a; Fernandes 2017) and fork-asymmetry accounts (Reichenbach 1956; Horwich 1987). Statistical mechanical accounts directly trace the temporal asymmetry of causation back to entropic features of the universe—typically the Past Hypothesis. Agency accounts trace the temporal asymmetry of causation back to temporally asymmetric features of agents, typically the fact that agents deliberate before they decide. Fork asymmetry accounts trace the temporal asymmetry of causation back to temporal asymmetries in macroprobabilistic structure, via principles such as common cause reasoning (Reichenbach 1956, Section 19). None of these programs has yet achieved widespread acceptance. But there is broad agreement, among reductionists, that causal asymmetry can be expected to align with the temporal asymmetry of entropy—a fact that may ultimately tie these programs together. For discussion of these programs and their relations, see Fernandes (2023).

In addition to arguments over particular explanations that reductionists offer, there are broader debates about the prospects for reductionism. On the positive side, reductionists argue that, regardless of whether time has an intrinsic direction, we need detailed explanations of how various temporally asymmetric physical phenomena arise—which is precisely the project that reductionists (in the broad sense) aim to pursue. On the negative side, anti-reductionists argue that even scientific explanations of the kind favored by reductionists rely on an intrinsic direction of time. Maudlin (2007: 130−5; see also Frisch 2014: 125) argues that an intrinsic direction of time is required to justify the asymmetric treatment of boundary conditions used in statistical mechanical explanations. If so, standard reductionist explanations presuppose an intrinsic direction of time. Most reductionists have remained unconvinced, responding that an initial constraint does not require an intrinsic direction of time (North 2011) and remaining skeptical that an intrinsic direction of time would do much to justify such a constraint.

5. Conclusion

Arguably, we experience the world as temporally directed. This appearance is enough, for some, to suggest that time itself has an intrinsic direction. Others tie their reasons for believing in time's intrinsic directedness much more closely to the form of fundamental physical laws. But for many, an intrinsic direction of time does little to explain the temporally asymmetric phenomena we are interested in and we should pursue such explanations without presupposing an intrinsic direction. But exactly what form these explanations should take and in what sense this amounts to a reduction of the direction of time remains largely unsettled.

Related Topics

The Passage of Time (Torrengo), Presentism and Eternalism (Ingram), Time and Thermodynamics (Shenker and Hemmo), Time in Quantum Mechanics (Allori), The Folk Concept of Time (Shardlow and Lee)

References

Albert, D. Z. (2000). *Time and Chance*. Cambridge, Mass.: Harvard University Press.

———. (2015). *After Physics*. Cambridge, Mass.: Harvard University Press.

Arntzenius, F. (2004). "Time-reversal operations, representations of the Lorentz group, and the direction of time." *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 35(1), 31-43.

Arntzenius, F., & Greaves, H. (2009). "Time-reversal in Classical Electromagnetism." *British Journal for the Philosophy of Science*, 60(3), 557-584.

Baron, S., Cusbert, J., Farr, M., Kon, M., & Miller, K. (2015). "Temporal Experience, Temporal Passage and the Cognitive Sciences." *Philosophy Compass*, 10(8), 560-571.

Callender, C. (2017). *What Makes Time Special?* Oxford: Oxford University Press.

———. (2021). "Thermodynamic Asymmetry in Time." In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Summer 2021 Edition). URL: https://plato.stanford.edu/archives/sum2021/entries/time-thermo/.

Earman, J. (1974). "An attempt to add a little direction to 'the problem of the direction of time'." *Philosophy of Science*, 41(1), 15-47.

Farr, M. (2020a). "C-theories of time: On the adirectionality of time." *Philosophy Compass*, 12, 1-17. <Further reading>

———. (2020b). "Causation and Time-reversal." *British Journal for the Philosophy of Science*, 71(1), 177-204.

Fernandes, A. (2017). "A Deliberative Approach to Causation." *Philosophy and Phenomenological Research*, 95(3), 686–708.

———. (2022). "How to Explain the Direction of Time." *Synthese*, 200(5), 1−30.

———. (2023). *The Temporal Asymmetry of Causation*. Cambridge: Cambridge University Press.
Frisch, M. (2014). *Causal Reasoning in Physics*. Cambridge: Cambridge University Press.
Ghirardi, G., Rimini, A., & Weber, T. (1986). "Unified dynamics for microscopic and macroscopic systems." *Physical Review D*, 34, 470−91.
Hoerl, C. (2014). "Do We (Seem to) Perceive Passage?" *Philosophical Explorations*, 17(2), 188–202.
Horwich, P. (1987). *Asymmetries in Time: Problems in the Philosophy of Science*. Cambridge, Mass.: MIT Press.
Ismael, J. (2012). "Decision and the Open Future." In A. Bardon (Ed.), *The Future of the Philosophy of Time*, London: Routledge, 149−68.
Lewis, D. (1979). "Counterfactual Dependence and Time's Arrow." *Noûs*, 13(4), 455-476.
Loewer, B. (2012). "Two accounts of laws and time." *Philosophical Studies*, 160(1), 115−37.
Mackie, J. L. (1974). *The Cement of the Universe: A Study of Causation*. Oxford: Clarendon Press.
Malament, D. B. (2004). "On the time-reversal symmetry of classical electromagnetic theory." *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 35(2), 295–315.
Maudlin, T. (2007). *The Metaphysics within Physics*. Oxford: Oxford University Press.
North, J. (2008). "Two views on time-reversal." *Philosophy of Science*, 75, 201–223.
———. (2011). "Time in Thermodynamics." In C. Callender (Ed.), *The Oxford Handbook of Philosophy of Time*. Oxford University Press, pp. 312--350.
Paul, L. A. (2014). "Experience and the Arrow." In A. Wilson (Ed.), *Chance and Temporal Asymmetry*. Oxford University Press, pp. 175-193.
Price, H. (1992a). "Agency and causal asymmetry." *Mind*, 101(403), 501–20.
———. (1996). *Time's Arrow and Archimedes' Point: New Directions for the Physics of Time*. Oxford: Oxford University Press.
———. (2002). "Boltzmann's time bomb." *The British Journal for the Philosophy of Science*, 53(1), 83–119.
———. (2011). "The flow of time." In C. Callender (Ed.), *The Oxford Handbook of Philosophy of Time* (Chap. 9: 276–311). Oxford: Oxford University Press.
Prior, A. N. (1959). "Thank Goodness That's Over." *Philosophy*, 34(128), 12−17.
Reichenbach, H. (1956). *The Direction of Time*. Berkeley: University of California Press.
Rovelli, C. (2018). *The Order of Time*. London: Allen Lane.
Stradis, A. (2021). "Memory, the fork asymmetry, and the initial state." *Synthese*, 199(3-4), 9523-9547.
Wallace, D. (2014). "The Arrow of Time in Physics." In H. Dyke & A. Bardon (Eds.), *A Companion to the Philosophy of Time*. Chichester, UK: Wiley, pp. 262–281.
Williams, D. C. (1951). "The Myth of Passage." *Journal of Philosophy*, 48(15), 457−472.
Zimmerman, D. W. (2007). "The privileged present: Defending an 'A-theory' of time." In T. Sider, J. Hawthorne, and D. Zimmerman (Eds.), *Contemporary Debates in Metaphysics*, 211–225. Wiley-Blackwell, Malden, MA.

Further Reading:

Albert, D. Z. (2000). *Time and Chance*. Cambridge, Mass.: Harvard University Press. (Recent classic for statistical mechanical explanations of temporal asymmetries.)

Loewer, Barry. (2012). Two accounts of laws and time. *Philosophical Studies*, 160(1), 115−37. (Summary of the debate between Albert and Maudlin.)

Maudlin, Tim. (2007). *The Metaphysics within Physics*, Oxford: Oxford University Press. (Maudlin's defence of an intrinsic direction of time.)

North, J. (2011). Time in Thermodynamics. In Criag Callender (ed.), The Oxford Handbook of Philosophy of Time. Oxford University Press. pp. 312--350. (Overview of explanations in statistical mechanics.)

Price, H. (2011). The flow of time. In C. Callender (Ed.), The Oxford handbook of philosophy of time (chap. 9: 276–311). Oxford: Oxford University Press. (A more historically-based discussion of the direction of time.)