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Weak Interactions: Asymmetry of Time or Asymmetry in Time?

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Abstract The paper analyzes the philosophical consequences of the recent discovery of direct violations of the time–reversal symmetry of weak interactions. It shows that although we have here an important case of the time asymmetry of one of the fundamental physical forces which could have had a great impact on the form of our world with an excess of matter over antimatter, this asymmetry cannot be treated as the asymmetry of time itself but rather as an asymmetry of some specific physical process in time. The paper also analyzes the consequences of the new discovery for the general problem of the possible connections between direction (arrow) of time and time-asymmetric laws of nature. These problems are analyzed in the context of Horwich's *Asymmetries in time: problems in the philosophy of science* (1987) argumentation, trying to show that existence of a time–asymmetric law of nature is a sufficient condition for time to be anisotropic. Instead of Horwich's sufficient condition for anisotropy of time, it is stressed that for a theory of asymmetry of time to be acceptable it should explain all fundamental time asymmetries: the asymmetry of traces, the asymmetry of causation (which holds although the electrodynamic, strong and gravitational interactions are invariant under time reversal), and the asymmetry between the fixed past and open future. It is so because the problem of the direction of time has originated from our attempts to understand these asymmetries and every plausible theory of the direction of time should explain them.

Keywords Weak interactions · Asymmetry of time · Asymmetry in time · Arrow of time · Arrow in time · Horwich

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1 Introduction

The asymmetry of time, that is possessing a distinguished direction (its "arrow"), seems to be one of the fundamental properties of time: we have many traces of the past—both in our memory and in the external world—but no traces of the future; events from the past influence those from the future, but we have no evidence of backward causation; the future seems to be open and we cannot definitely change the past. The problem of the asymmetry of time consists in examining the question of whether time really has a distinguished direction and, if it has, in explaining what is the origin of this direction, and especially of the three aforementioned asymmetries.

We trust in physics and believe that it is able to explain all physical phenomena; so if the asymmetry of time is real and objective and does not depend on accidental initial and boundary conditions, then it seems that it should be manifested in some time asymmetry within our laws of nature. The paper analyzes the general problem of the existence of such connections, and a special case of this problem related to the law governing weak interactions because it is at present the only known physical law which is temporally asymmetric and—what is more—physicists have recently attained direct experimental confirmation of the time–reversal violation of weak interactions. The second section of the paper briefly recalls physicists' struggles with the time-asymmetry of weak interactions ending with the recent discovery, the third one analyses the philosophical consequences of recent experiments with weak interactions concerning the asymmetry of time and the general problem of possible connections between the direction (arrow) of time and time-asymmetric laws of nature. The last section contains conclusions.

2 The Direct Evidence for Time–Reversal Violation of Weak Interactions

A plausible test of time–reversal symmetry violation needs an asymmetry under the interchange of initial and final states in the dynamical evolution of a physical system. Thanks to a recent search performed at SLAC (the Stanford Linear Accelerator Center) we have at last achieved an unequivocal *direct* confirmation of the time–reversal violation of weak interactions (see Lees et al. 2012). "Direct" here means "without relying on assumed relationships with other fundamental symmetries". This is an important fact as we have known since 1964 that weak interactions violate a combination of parity inversion with charge conjugation CP,[1] and using CPT theorem (see Lüders 1957), according to which all local Lorentz invariant quantum field theories are invariant under the simultaneous operations of charge conjugation C, parity inversion P, and time–reversal T, we could from this *indirectly* infer time–reversal invariance violation of weak interactions. But indirect confirmation is, of course, only conditional confirmation and as such is not as sure as direct confirmation, so it was possible to remain skeptical about this outcome as it took place, for example, in the case of Horwich (1987).[2]

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[1] See Christenson et al. (1964) and recent experimental measurements of CP violation in Abouziad et al. (2011) and Beringer et al. (2012). In the operation of charge conjugation C, particles are interchanged for antiparticles, in the operation of parity inversion P, particle positions are reflected [(x, y, z) → (−x, −y, −z)], and in the operation of time–reversal T, time is reflected (t to −t). Roberts (2015) analyzes various approaches to T-violation (the violation of temporal symmetry).

[2] Horwich's argumentation will be analyzed later.

It was not easy to attain this result because it is not easy to achieve a pure time–reversal symmetry violation case without reference to *CP* violation.[3] So, for example, in the earlier experiment performed at CPLEAR (see Angelopoulus et al. 1998), which was supposed to measure the direct time–reversal symmetry violation, K^0 transitions to antiK^0 and antiK^0 transitions to K^0 were used. However, as was noticed by Bernabeu et al. (2012), who suggested the experiment performed at SLAC, the measured asymmetry between the probabilities of these decays cannot be interpreted as the direct violation of time–reversal invariance: "[t]he measured asymmetry among the probabilities $K^0 \rightarrow$ antiK^0 and anti$K^0 \rightarrow K^0$ cannot be interpreted as such since, being *CPT*-even transitions, *CP* and *T* are experimentally identical, no matter whether there is *CPT* invariance or not" (Bernabeu et al. 2012, 13). In a similar vein, Wolfenstein claimed "[t]he CP LEAR result could then be interpreted as evidence that this process would violate time reversal invariance, as well as CP invariance."[4]

In the experiment performed at SLAC, to avoid the above-mentioned ambiguity, entangled B^0–antiB^0 system produced in positron–electron ($e+$ $e-$) collisions was used. The experimenters compared the probabilities of anti$B^0 \rightarrow B^-$; $B_+ \rightarrow B^0$; anti$B^0 \rightarrow B_+$; and $B^- \rightarrow B^0$ transitions to their *T*-conjugate and when time–reversed pairs were compared, they found discrepancies in the decay rates.[5] This was the first observation of time–reversal invariance violation in any system through the exchange of (time–reversed states of) the initial and final states in transitions that can only be connected by a *T*–symmetry transformation. But what are the philosophical consequences of this result?

3 Is Time Itself Asymmetric Because of Existence of Time-Asymmetric Laws?

We now have time–asymmetric physical law, whose status as a directly confirmed (or corroborated) scientific hypothesis is exactly the same as other physical laws.[6] Does it mean that we have at last found an arrow (or asymmetry) *of* time itself?[7] This is a tempting idea to bind together the arrow of time with a time–asymmetric physical law and it is not surprising that such a conception has its adherents.

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[3] See Wolfenstein (1999a), and Bernabeu et al. (2012).

[4] Wolfenstein (1999b, 508). See also Wolfenstein (1999a).

[5] The B_+ and B_- states are defined as the neutral B states filtered by the decay to *CP* eigenstates $J/\psi K_L^0$ (*CP* even), and $J/\psi Ks^0$ (for *CP* odd), respectively. The transitions involved in the experimental tests of *CP* and *T* symmetries are different: a test of *CP* symmetry can be done with the $J/\psi Ks^0$ final state only, while a test of *T* invariance necessarily involves both $J/\psi Ks^0$ and $J/\psi K_L^0$ final states. See Bernabeu et al. (2012) and Lees et al. (2012).

[6] According to Albert (2000, 14), contrary to what is commonly believed, all fundamental physical theories, such as classical electrodynamics, quantum mechanics, relativistic quantum field theory, and general relativity are *not* invariant under time–reversal. However, as it was shown by Earman (2002), Albert made use of a highly non-standard interpretation of time–reversal invariance that distorted his analysis; while we usually say that a theory is time reversible if whenever a sequence of states S_1, S_2, … S_n is possible according to that theory, then the reverse sequence of *time reversed* states $T(S_n)$, $T(S_{n-1})$,… $T(S_1)$ is also possible according to that theory (where T is a time–reversal operator), Albert assumed that we should not use time reversed states in this requirement. See also Malament's (2004) critique of Albert's thesis regarding classical electromagnetic theory.

[7] Such a suggestion is made, for example, by Zeller (2012) in the title of his essay: "Particle Decays Point to an Arrow of Time".

3.1 Horwich's Gambit

Paul Horwich is an important example of a philosopher who maintained that "time–asymmetric laws of nature are a *sufficient* condition for time to be anisotropic".[8] He was convinced that "[i]f what is definitely a law is time-asymmetric, then time is definitely anisotropic" (Horwich 1987, 46).

Horwich proposed some interesting arguments in favour of this. He assumed that the anisotropy of time should consist in an intrinsic dissimilarity of the past and future directions: their having different *intrinsic* (vs. non-intrinsic or relational) properties, where "the intrinsic properties of an object were those expressible by predicates that are composed of natural predicates, contain no names, and have no quantifiers except those restricted to range over just the object itself and its part".[9] Horwich claimed that such a qualification of intrinsic properties is sufficient to assume the dissimilarity between two directions of time, that is, the asymmetry *of time itself*, and was convinced that it should manifest itself in some time asymmetry within our laws of nature:

Thus we are supposing that there must be something about time *itself* that explains the difference. Thus a sufficient condition for there to be an intrinsic dissimilarity between the past and future direction of time is that they be distinguished by laws of nature. And this will be manifested in some difference between the ways in which *earlier* and *later* function in the laws of nature.[10]

He thought that this excluded grounding the asymmetry of time in the known at present de facto asymmetries because in such a case non-intrinsic properties—initial or boundary conditions of the universe—are involved; these only constitute asymmetries *in* time. However, "we cannot preclude the possibility of (future) physical theories in which some of time's intrinsic features will be treated as de facto, that is, as not required by law" (1987, 42) and that is why Horwich, at the same time, claimed that there is no reason to regard the existence of time–asymmetric laws of nature as *necessary* condition for the anisotropy of time.

To this short presentation of Horwich's view it should also be added that he rejected the "moving now" conception of time as a source of the asymmetry of time because he claimed (after McTaggart) that such a conception leads to a contradiction,[11] and declared to be an adherent of eternalism, according to which the past, the present, and the future are equally real, and there is no passage of time. In consequence, the flow of time cannot be, according to him, a source of the asymmetry of time.

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[8] See Horwich (1987, 42). Horwich was certain that "the existence of time–asymmetric laws of nature is generally taken to guarantee time's anisotropy" (1987, 39), although, for example, Sklar (1974) and Earman (1974) had not agreed with such a position (I shall present Sklar's motivation later). Henry Mehlberg (1961) was also among these philosophers who bound together the asymmetry of time with existence of time-asymmetric laws. Because Mehlberg didn't find such an asymmetric law, he insisted that time is symmetric. Horwich follows his path.

[9] "Natural" predicates are "predicates that play a role in articulating laws of nature" (Horwich 1987, 40).

[10] Horwich (1987, 41, 54–55).

[11] Horwich (1987, 16–25). Horwich only accepted the second part of McTaggart's (1908) argument, according to which the "moving now" model of time is incoherent: ascribing absolute *A*-properties (or *A*-determinations) *past*, *present*, and *future* to any event (forming this way *A*-series of time) leads to a contradiction because every event should have all of them while it can possess only one (they are mutually exclusive)—see fn. 28 for the critique of this argument by Savitt (2001). Horwich rejected the first part of McTaggart's argument which was intended to show that time and *B*-series of time (ordered with respect the relation *later than*) exist if events are located in a real *A*-series.

It could seem that if Horwich assumed that the existence of a time–asymmetric law of nature is a sufficient condition for time to be anisotropic and because he was aware of *CPT* symmetry and the *CP* symmetry violation of weak interactions in physical experiments, then he should have claimed that time is asymmetric but, surprisingly enough, he didn't and instead argued that "the current empirical evidence indicates that time itself is symmetric" (1987, 38). He didn't claim that time is asymmetric because, according to him (1987, 56):

1. The time–reversal invariance violation of weak interactions had not been directly confirmed and neither the experimental nor the theoretical assumption involved in the argument based on *CP* asymmetry are beyond question;
2. Even if time–reversal invariance violation of weak interaction were true, it could turn out to be merely a de facto asymmetry, which does not involve time-asymmetric laws of nature;
3. The *CPT* theorem may be false.

What can we say about these objections? Now the time–reversal symmetry violation of weak interactions has been directly confirmed at the experiment performed at SLAC so the first objection is no longer valid. *CPT* theorem, although no longer necessary for the proof of the time–reversal symmetry violation of weak interactions, is theoretically without reservation (see Lüders 1957) and its conclusion—*CPT* symmetry—was experimentally confirmed as well, so there is neither a theoretical nor an experimental—at least based on presently available data—reason to support the third objection.[12] The time–reversal symmetry violation of weak interactions and *CPT* symmetry are not, of course, proved in the sense in which this word is used in mathematics but its status as a directly confirmed (or corroborated) scientific hypothesis is exactly the same as other physical laws.

There is a slightly more difficult problem with Horwich's second objection: that the time–reversal symmetry violation of weak interactions can turn out to be merely a de facto asymmetry, cannot be a priori excluded. We remember, for example, that in the case of the second law of thermodynamics, a regularity which seemed to be lawlike turned out to have a de facto character when a macroscopically observable thermodynamic behavior of physical systems was explained as an approach to the equilibrium of microscopic atomic systems.[13] The point is, however, that to make this objection valid, Horwich should show us how it can be demonstrated that the time asymmetry of weak interactions really has a de facto character; that the law governing weak interactions is indeed lawlike is a received view for physicists and philosophers of science which fact is acknowledged by Horwich.[14] What he claims is that what we assume to be a law *can possibly* turn out to be de facto. However, if somebody claims that the received view is not justified, the burden of proof lies with him; this is not enough to claim that it *can* be wrong. Not only has Horwich failed to justify his objection, but, what is more, it is hard to see how it can be done; a similar

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[12] *CPT* symmetry was experimentally confirmed, inter alia, by Fermilab (Abouziad et al. 2011). See also the reviews of particle physics in Beringer et al. (2012).

[13] See, for example, Huang (1987, 85–91); and Sklar (1974, 379–394).

[14] For example, Bernabeu et al. (2012) write about their paper entitled "Time Reversal Violation from the Entangled B^0–antiB^0 System" in the conclusions: "This work concerns the study of microscopic Time Reversal Violation in the fundamental laws of physics." In a similar vein, Maudlin (2007, 120) writes: "Let's return for the moment to the violation of CP invariance displayed in neutral kaon decay. We noted above that this phenomenon seems to imply that the laws of nature are not Time Reversal Invariant in any sense, and hence that the laws themselves require an intrinsic asymmetry in time directions, and hence that space–time itself, in order to support such laws, must come equipped with an orientation."

"microscopic" maneuver as in the case of thermodynamics seems to be impossible here because we are already on the microscopic level. It is also hard to see any involvement of the initial or boundary conditions in the phenomena of the temporal asymmetry of weak interactions.

So it seems that Horwich and everybody who would like to follow his way of binding together the asymmetry of time with time–asymmetric physical laws should claim that time is asymmetric because of the time asymmetry of weak interactions. It seems, however, to be somewhat bizarre to connect the arrow of time with weak interactions. Time really appears to be asymmetric because the past is fixed and the future is (or seems to be) open; we have traces of the past and no traces of the future; causes precede effects and we do not find cases of backward causation, but it seems something implausible to bind these with the weak interactions because we do not find any possible way in which weak interactions could be involved in the phenomena mentioned above.[15] It was noticed a long time ago, shortly after the discovery of *CP* asymmetry violation by Feynman ([1967], ch. 5), that the distinction between the past and the future cannot depend on asymmetries of weak interactions because in normal situations, for example when we are speaking, writing, walking, watching TV etc., weak interactions are not involved. This is not, however, the end of the story.

3.2 Sakharov to Rescue

An adherent of connections between the asymmetry of weak interactions and the asymmetry of time could defend his/her position by claiming that contemporary physics shows us that the asymmetries of the weak interactions are not without impact on our world; on the contrary, it seems that this impact was so significant that it cannot be overestimated. Namely, the universe which we live in and which we observe is composed almost entirely of matter with little or no antimatter.[16] This is the problem with the so-called *baryogenesis*, which consists of an explanation of which physical processes led to the existing asymmetry between matter and antimatter in the universe. In 1966, Andrei Sakharov tried to explain the occurrence of the asymmetry with respect to the number of particles and antiparticles, or baryons and antibaryons, as a consequence of the violation of *CP* invariance in the nonstationary expansion of the hot universe during the superdense stage, which had to influence—according to him—the difference between the partial probabilities of charge–conjugate reactions. He proposed three necessary conditions which must be satisfied to explain the asymmetry between baryons and antibaryons in the early universe, resulting in the lack of antimatter bodies in the universe today:

    i.   baryon number violation;
   ii.   *C* and *CP* invariance violation;
  iii.   deviation from thermal equilibrium in the early universe.[17]

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[15] A similar position is vindicated by Sklar in his works, for example, in ([1974]).

[16] Another important phenomenon on which the weak interactions can have an impact is an increase in the temperature of magma and volcanic eruptions—see Penrose (Penrose [2004], ch. 34.10).

[17] See Sakharov ([1967]), Riotto and Trodden ([1999], 38).

 The baryon number violation [condition (i)] is a necessary condition to produce an excess of baryons over antibaryons. C and CP invariance violation [condition (ii)] are also needed so that the total rate for any process producing an excess of baryons is not equal to the rate of the complementary process producing an excess of antibaryons.[18] The third condition should be satisfied since in thermal equilibrium there would be no generation of net baryon number because of CPT symmetry.[19] Different possible scenarios are considered which are supposed to ensure the satisfaction of Sakharov's conditions and an electroweak baryogenesis utilizing CP violation of the weak interactions is one of most important among them. Admittedly, the CP invariance violation of weak interactions is much too small to account for the observed baryon asymmetry of the universe but this scenario can be extended by an additional source of CP violation such as, for example, supersymmetry.[20]

Now, because CPT is assumed to be a good symmetry, the CP violation of some interactions is equivalent to the T violation of these interactions. So it is possible to claim that the time symmetry violation of the weak interactions had indeed a great impact on our world being a source (or one of possible sources) of the baryon's asymmetry. But does it allow us to bind together a direction of time with weak interactions? It is doubtful. For let us give the advocates of binding together the arrow of time with the asymmetries of weak interactions as much as possible, namely let us assume that the T violation of weak interactions (equivalent to CP symmetry violation if the CPT symmetry holds true) is a necessary condition for the baryon asymmetry of the universe, that is it is a necessary condition for the existence of our world in the form known to us with the excess of matter over antimatter. Does it give us any explanation of the main asymmetries of the worlds, that is the asymmetry of traces, the asymmetry of causation and the asymmetry between the fixed past—the (probably) open future? Unfortunately, no possible mechanism responsible for these asymmetries and having its source in weak interactions can be seen, so Feynman's remark (that the distinction of the past and the future cannot depend on asymmetries of the weak interactions because in normal situations the weak interactions are not involved) seems to remain valid. Anyway, the burden of proof that the excess of matter over antimatter explains the lack of the traces of the future, lack of the backward causation and openness of the future lies with the adherents of such a view.

Perhaps, somebody would like to claim that *there is* yet another—unknown at present—possible mechanism connected with the weak interactions which is responsible for the above-mentioned asymmetries. However, in such a case, it is not enough to maintain such a claim; the burden of proof of existence of such a connection lies with him/her. Otherwise, every our theory could be undermined by a claim that there is another possible—yet unknown at present—mechanism connected with XYZ (whatever you want) which can undermine this theory.

3.3 Detour Strategy

There is another possible strategy to tackle the problem of the relationship between the asymmetry (or symmetry, as it is claimed by Horwich) of time (on the one hand) and the asymmetries of traces, causation and the fixed past—the open future (on the other hand): trying to treat these problems as independent. The strategy forces its adherents to look for

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[18] The thermal average of the baryon number operator B, which is odd under both C and CP transformations, is zero unless those symmetries are violated—see Riotto and Trodden (1999, 38).

[19] See Riotto and Trodden (1999, 38).

[20] See Riotto and Trodden (1999, 44–45, 71).

sources of asymmetries we meet in everyday life somewhere other than in (symmetric or asymmetric) time. Such a strategy, when successful, would allow in a special case of an adherent of connections between (a)symmetry of time and (a)symmetry of physical laws *not to bind together* the asymmetry (or symmetry, as it is claimed by Horwich) of weak interactions with asymmetries of everyday experience.

This is exactly the strategy chosen by Horwich, which is supposed to allow him to claim that time is symmetric in spite of the obvious asymmetries we encounter every day. Although Horwich was wrong in his assessment of the asymmetry of weak interactions, as the recent experiment at SLAC shows, his strategy—when successful—would free its believers from the duty to show connections between the asymmetry of weak interactions and asymmetries of everyday experience. It transpires, however, that this strategy is hard to implement; at least—as I shall try to show—Horwich's trial is implausible.

He did not explain why the past is fixed and the future seems to be open; instead of this asymmetry, he pondered why we care much more about the future than about the past. He proposed the following explanations: we care much more about the future than about the past because of the selectional value of such asymmetric preferences; our past–oriented care and desires cannot be fulfilled and are useless although those that are future–oriented can be fulfilled and help us to survive and to adapt to our environment.[21] Horwich is obviously right that our past–oriented care and desires cannot be fulfilled and are useless, yet it is also obvious that it is impossible not because such past–oriented actions do not improve our situations but because we *cannot* change the past—it is fixed. So the problem with this argumentation is that it is grounded in the *implicit* assumption that the past is fixed while the future is (probably) open and can be changed; otherwise our expectation that our concern for the future is conducive to our survival and reproduction would be pointless. But the asymmetry between the fixed past and the open future is exactly one of these asymmetries which Horwich should have explained in the first place and not taken for granted. Because he did not explain the origin of this asymmetry, it means that his argumentation is implausible and ends up begging the question.

Horwich tried to explain the asymmetry of traces and, especially, why we know more about the past—having so many recorded traces of it (e.g., memory, writing, photographs, tape recordings, footprints, fossils, and paintings)—than about the future, which provide us with no recorded traces, by referring to a fork asymmetry. The phenomenon of recording is, according to him, an instance of this pattern of events that he identified as a "normal fork" which consists in the fact that regularly associated events must have a common cause but need have no joint effect.[22] This explanation, however, seems again to be implausible for two reasons. Firstly, although we have sometimes doubled, or multiplied traces of some events from the past, as a matter of fact, traces to be traces *need not be doubled*. I remember what I thought yesterday, and before yesterday (and so on), and I need no more evidence of these processes to be sure what I thought about. Sometimes, of course, I can make notes or some recording on my computer but this, in fact, is not needed if I believe in my memory. A policeman can find a single fingerprint in a place where an offence is committed and should he really think that it is not a trace because it is solitary? An anthropologist can find a single million-year-old fossil bone—with conceivably no other traces—that can bring about a revolution in science even if it is impossible to find another fossil of this type. A single tape recording or a photograph can be, taking for granted that

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[21] Horwich (1987, 196–198). He follows here Mehlberg (1961).

[22] Horwich (1987, ch. 5). Following Earman (1974), he rejects the explanation of time asymmetry of traces based on the asymmetry of entropy.

they are not falsified, documentation of important happenings from the past which we believe in. These examples, and many others, show that, contrary to what Horwich claims, the phenomenon of recordings does not consist in the "causal connectedness of correlated events". In fact, Horwich did not appeal to the fork asymmetry itself in his explanation of asymmetry of our knowledge and asymmetry of traces.[23]

Secondly, the fork asymmetry could only explain why we have more traces of the past than traces of the future (if we had such traces) but it does not explain why we do not have traces of the future *at all*; the fork asymmetry in no way blocks the occurrence of traces of the future.

Our special kind of experience is an experience of the flowing of time. For the adherent of the objectivity of the flow of time, this phenomenon is a source of the asymmetry of time. For Horwich, of course, the passage of time cannot play this role and is only an illusion. He tried to show how we can *create* this illusion—according to him, our "sense of the passage of time" is the effect of two factors: phenomenological and linguistic.[24] First, we are aware of sequences of experiences in which events that are initially anticipated are then sensed and subsequently remembered. Just as these sequences of experiences, ordered with the relation "later than" or "earlier than," we are conscious from "different temporal perspectives" or "different vantage points." In the second place—according to Horwich—our conventions concerning the concepts of "motion" and "direction" lead to a particular way of describing the array of states of mind as "movement through time" into the future.

The main flaw of this argument is that Horwich was not able to explain the origin of this *changing* "temporal perspectives" or "vantage points"—how is it possible that, in different moments of time, the same subject can anticipate, then sense, and subsequently remember the same event? If he had been able to explain from his eternalist's perspective the lack of traces of the future, a presence of the traces of the past and the lack of the traces of the future at every moment of time could have imitated a movement of the vintage points and introduced alleged (although not real) direction of time but, as I tried to show, he did not explain why there are no traces of the future.[25] Thus one can easily become suspicious that in speaking of different "temporal perspectives" Horwich has simply smuggled the passage of time into his reasoning, something what he wanted to explain. It is exactly the moving of different "vantage points" or "temporal perspectives" that he as an eternalist cannot *posit* but should *explain* as to how we produce it. What Horwich actually gave us is a description of how we *experience* the passage of time, whatever it is, but not an explanation of how we *create* an illusion of it in our mind. Thus, just as in the case of his explanations of the origins of our concern for the future and the asymmetry of our knowledge, Horwich's argumentation is based on a fallacy of *petitio principii*.

The last element of Horwich's strategy which I would like to examine is his explanation of the asymmetry of causation. He maintained that explanation is theoretically prior to causation and that the direction of physical explanation yields the directions of causation. He offered a range of different a posteriori answers to the question of why we believe in the future orientation of causation and use it in our explanations:

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[23] Healey (1991, 128) first noticed that Horwich had nowhere appealed to the fork asymmetry itself in his explanation of the asymmetry of our knowledge.

[24] Horwich (1987, 33–36) made use of Miller's (1984) elucidation of Husserl's *Phenomenology of Internal Time-Consciousness*.

[25] Horwich, as an eternalist, should have also explained why we persist through time, keeping our numerical identity being wholly present at each moment, that is why we endure, but he didn't. I will not pursue this question in the paper.

1. Causation is defined, in part, by the principle that correlated events are causally connected, and this, given the fact that there are no inverse forks, determines the fact that causation is future oriented.
2. Causation is defined through its association with our experience of deliberation and control, and our voluntary actions are performed only for the sake of future events.
3. Causation is defined, in part, by the idea that a cause is ontologically more basic than its effect and because we have traces of the past but not of the future we tend to think that the past has more reality than the future. Hence, we assume that the past is causally prior to the future.[26]

Unfortunately, these explanations are unconvincing. The first one is mistaken: we do not connect the direction of causation with the directionality of forks: firstly, we have a good sense of the direction of causation even if there is (or would be) only one effect of some cause. And secondly, let us assume that we have an inverse fork, for example a case (similar although not exactly the same as the case of overdetermination) when two people are—by accident—simultaneously shooting a third and causing his death, and both these shots are necessary to produce this effect. Will we say in such a case that causation is past oriented because of an inverse fork? The answer is, of course, negative.

The explanations (2) cannot be accepted as introducing directionality to causation granted that time is symmetric (Horwich's assumption) because it is based on the hidden time-asymmetric assumption saying that the past is fixed and the future is open, as I tried to show above. I also attempted to show that Horwich did not explain why there are no traces of the future, hence (3) is implausible as well. Therefore Horwich's explanation of the asymmetry of causation is partially mistaken and partially based on a fallacy of *petitio principii*.

Thus Horwich's strategy has failed to treat time as symmetric and to explain the asymmetries of traces and our knowledge, the asymmetry of causation, and the asymmetry between the fixed past and open future without—as he declared—referring to the asymmetric time. It is symptomatic that all his arguments contain the hidden assumption about the existence of time–asymmetric phenomena although Horwich regarded time as symmetric: the asymmetry between the fixed past—open future; lack traces of the future (while we have many traces of the past); and the moving (toward the future) vantage points from which we are experiencing the world. The problem which he encountered is not accidental; when we try to explain the asymmetries which we know from everyday life we first of all want to refer—at the deepest level—to physical laws and these are symmetric, with the exception of weak interactions which are, as pointed out by Feynman and others, not involved in normal everyday situations. The fundamental difficulty here is that it is impossible to receive time–asymmetric phenomena from time–symmetric assumptions (if we ignore accidental initial and boundary conditions), and in the case when Horwich's main tool—the fork asymmetry—failed to do the job, the whole endeavor had to fail.

3.4 Sklar's General Argument

The problem of the arrow of time—which should be recalled here—originated from our attempts to understand and explain the asymmetries of traces, causation and the asymmetry between the fixed past and open future, and every solution to the problem of the direction of time—symmetric or asymmetric one—should explain the source of the last three

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[26] Horwich (1987, 143–144, 202–203).

asymmetries. From the consideration above, it follows that weak interactions and the law governing them do not provide us with such an explanation and should be treated only as a kind of asymmetry *in* time but not as a source of asymmetry *of* time.

I argued above that the direction of time cannot be based on a time–asymmetric law governing weak interactions. Even if it turned out that recent and earlier experiments concerning weak interactions were erroneously carried out, we would not change our opinion about asymmetries of traces, causation and the asymmetry between the fixed past and open future. So the existence of this time-asymmetric physical law seems not to be a sufficient condition for time to be anisotropic and Horwich's reasoning appears to be incorrect. Nevertheless, somebody could try to strengthen Horwich's sufficient condition in the following way:

> time-asymmetry of *all* physical laws is a sufficient condition for time to be anisotropic

to include other interactions which are involved in phenomena of everyday life. It can be shown more generally, however, that no time–asymmetric physical law—even if all of them were time-asymmetric—can provide us with the grounds for the asymmetry of time. Such a line of argumentation was proposed by Sklar.[27] Let us suppose—argued Sklar—even that for every isolated system in the universe times related to one another by temporal priority are times at which the systems have states that are asymmetrically related to one another by a nontemporal relation and are such that their time–reversal can never appear in the reversed time order by the laws of nature. Does it give us any explanation with regards to the direction of time? No—answered Sklar—because the only thing which we would know in such a case would be that the reversed time order of the time-reversed states would not be compatible with the laws of nature. We can imagine a possible world consisting of the time–reversed states of the actual world in the reversed time order, which would be governed by its own laws that would be time–reversed laws of the actual world. If we would like to choose which laws are true (in our world), we can only do it—it seems—by checking the behavior of the physical system in our world.

The main point of Sklar's argument is that what real or possible time–reversal noninvariant laws give us is the knowledge about the order and the lawlike behavior of physical systems; they do not give us any explanation of what the direction of time is and do not give us any insight in it, and especially they do not explain what is the origin of the asymmetry of traces, the asymmetry of causation and the asymmetry between the fixed past and open future. Such an argument seems to be sound in the case of laws which are known to us at present; it is hard to imagine that any change of this sort that weak interaction would turn out to be time–reversal invariant or, alternatively, that if our other physical laws turned out to be time–reversal noninvariant then it would give us any explanation of what the direction of time is. Such a change would only mean that the reversed time order of the time–reversed states of actual states would be compatible with these new laws and would not be compatible with the laws we know at present. However, Sklar's argument can turn out to be insufficient in the case of new laws which we are currently searching for. In such theories, a role of time can be fundamentally different, as it is, for example, in the theory developed by Rovelli where time plays no role at all (see Rovelli 2011). Nevertheless, it will be only possible to verify Sklar's argument in the context of this and similar theories when they are fully developed. Anyway, taking into account the present state of our

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[27] Sklar (1974, 401–402). Earman (1974, 31) also claimed that that no time–asymmetric physical law can provide us with a basis for the asymmetry of time.

knowledge, the time-asymmetry of a physical law does not seem to be a sufficient condition for time to be anisotropic and Horwich's reasoning appears again to be incorrect.

3.5 Horwich's Main Assumption Revisited

It is interesting to examine where mistakes in Horwich's reasoning could have been made. His starting point, that the anisotropy of time would consist in the intrinsic dissimilarity of two directions: their having different intrinsic (for time itself) properties, seems to be good but, nevertheless, there are—I think—two flaws in his further argumentation. Firstly, he rejected the metaphysical theory of the direction of time founded on the idea of the flow of time too quickly. Too quickly, I think, because his refutation of our common solution to the problem of the direction of time, which is well grounded in everyday experience, should be based on much more solid foundations than McTaggart's controversial argument.[28] Although there are some other interesting arguments which could be discussed instead, none of them seems to be compelling. There is, however, no place here to examine this problem.[29]

Secondly, Horwich's characterization of "intrinsic properties", which was crucial for his reasoning intended to determine a sufficient condition for time to be anisotropic, is obscure and ambiguous in the case of time. He described as intrinsic properties—I recall—those expressible by predicates that are composed of natural predicates, contain no names, and have no quantifiers except those restricted to range over just the object itself—that is time itself—and its part (1987, 40). But he also added that his assumption according to which the anisotropy of time should consist in an intrinsic dissimilarity of the past and future directions (their having different *intrinsic* properties) does not imply a commitment to substantival (or absolute) time (1987, 47). Horwich claims that the question of whether time is (an)isoptropic can plausibly be interpreted as a question about the resemblance (or difference) between the relations *later* and *earlier*, and these relations can be understood in a Leibnizian way and can be investigated by analyzing physical laws. The point is that such a characterization of the intrinsic properties of time is insufficient and ambiguous, which can be best seen in the case of weak interactions; how could we get to know on the basis of this description whether the properties of weakly interacting elementary particles refer to *time itself* and its parts (and the predicates describing them range over them) rather than that they are specific for *these* specific particles and *these* specific interactions? In the first case, we would really have the asymmetry *of* time, in the second, however, only the asymmetry *in* time of some specific physical processes.

Horwich thinks that the anisotropy of time can be inferred from a temporal asymmetry of *some* physical law. At first glance, this argument seems to be plausible because we make similar reasoning—let us recall—in the case, for example, of the homogeneity of space and time which can be inferred of from the invariance of physical laws under spatial and

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[28] Savitt (2001) noticed, for example, that the copula "is" used in the sentences "Every event is past, present and future" and "Every event is past or present or future (and can only have one of these *A*-properties)" is not univocal—with the tenseless sense in the first and the tensed in the second sentence—and therefore there is no contradiction involved in accepting both.

[29] For example, a metaphysical solution to the problem of the direction of time which makes use of a notion of directional *dynamic existence* is proposed in Gołosz (2015); as a result of such a conception of existence, the direction of time can be treated as a consequence of a special form of the existence of all objects which our world consists of. Such an approach to presentism allows us to avoid the triviality problem and to treat presentism, that is the view according to which only the present exists and there is a flow of time, as a consistent, homogenous view consisting of only one thesis.

temporal translations, or of the isotropy of space which can be inferred from the invariance of these laws under the spatial rotation. There is, however, a fatal flaw in Horwich's reasoning because there is a logical gap between the temporal asymmetry of *some* physical law and asymmetry *of* time itself; the first can hold even if the other does not, as can be best seen in the fact that other physical interactions which are active on different levels of physical reality are invariant under time–reversal: should we assume that they are active in *different* spacetime than weak interactions?

His argument would be more plausible if other interactions were also temporally asymmetric as it is in the above mentioned cases of the universal invariance of all physical laws under spatial and temporal translations, or the invariance of these laws under spatial rotation—in such a case we could make a more plausible abductive step from the temporal asymmetry of all physical interaction to asymmetry *of* time. The fact that the electrodynamic, strong and gravitational interactions are invariant under time–reversal seems to give us a strong evidence that the time asymmetry of weak interactions is *only specific* to the weakly interacting particles and that Horwich's "sufficient condition" is, in fact, not sufficient.

Perhaps, then, Horwich should postulate that the time-asymmetry of *all* physical interactions is a sufficient condition for time to be anisotropic. However, as it was mentioned before, Sklar's argument of a hypothetical world in which all physical processes are irreversible by the laws of nature seems to show that even the time-asymmetry of all physical laws could not explain the observable temporal asymmetries of the world, such as the asymmetry of traces, the asymmetry of causation and the asymmetry between the fixed past and (probably) open future. So—based on our current state of knowledge—it seems that even such a risky maneuver would not help Horwich to maintain his claim about the connections between the direction of time and time-asymmetric laws of nature.

4 Conclusions

I have tried to show that Horwich's claim that the direction of time is grounded in time-asymmetric laws of nature—concerning weak interactions and other interaction as well—is implausible or—strictly speaking—that the existence of a time–asymmetric law of nature is *not* a sufficient condition for time to be anisotropic. It is not so because there seem to be no connections between the temporal asymmetry of physical laws—and temporal asymmetry of weak interactions especially—and the lack of traces of the future, the lack of backward causation and the lack of possibility to influence the past while at the same time we have traces of the past, future-oriented causation which can influence the future. These asymmetries are fundamental for our experience and for our world, and cannot be simply eliminated by any imaginable subjectivistic maneuver because no such maneuver can make it possible to infer these everyday time-asymmetric experiences from phenomena in which time-symmetric strong, electromagnetic and gravitational forces are involved, only if we do not want do invoke accidental initial or boundary conditions. The asymmetry of weak interactions does not help us to explain these time-asymmetric experiences, nor can this perform a possible change in our assessment of the symmetry of strong, electromagnetic and gravitational forces.

The difficulty of the problem of the asymmetry *of* time which results from the very specific role of time in our experience and in our world and which is very different from this played by space we can find traces of—and we can act causally on (providing that we

have enough time to do this)—what is up and down, left and right, in front of and behind us while at the same time we cannot causally affect the past. The asymmetry of weak interactions does not help us to change this situation nor is it conceivable at present that any other possible asymmetric law of nature can do this. Therefore instead of Horwich's "sufficient condition" for time to be asymmetric, a more fundamental requirement should be recalled and put forward: every plausible solution to the problem of the direction *of* time should explain what is the source of the asymmetry of traces, the asymmetry of causation and the asymmetry between the fixed past and (probably) open future in a credible way. Horwich's solution does not satisfy this condition. Nor does any conceivable theory involving weak interactions do so and thus it seems that the time-asymmetry of weak interactions is only an asymmetry *in* time.

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