*Journal of Scientific Exploration*, Vol. 33, No. 1, pp. 61–72, 2019 0892-3310/19

**REVIEW**

# The Case for Advance Wave Causality

Charles W. Lear

Retired Adjunct Professor, Department of Physics, Weber State University, Ogden, Utah, USA
charleslear@weber.edu

Submitted July 12, 2017; Accepted January 9, 2019; Published March 30, 2019

DOI: https://doi.org/10.31275/2019.1232


**Abstract—**We seek to strengthen the hypothesis of time reversal of cause and effect, or the bipolar causal nature of advanced and retarded waves. The hypothesis is not directly testable, at least with existing technology, so the argument is based on a priori reasoning. It provides a basis for rationalizing entanglement and for the Wheeler–Feynman absorber theory. Alternative hypotheses are given and compared to show justification.

*Keywords:* advance wave—retrocausation—causal time reversal—Occam's razor—entanglement—Wheeler–Feynman absorber

## Introduction

The hypothesis of time symmetry of causality is problematic. We put forth some effort to explain and justify it. The argument has a two-fold thrust. The first centers on the phenomenon of entanglement, for which causal time reversal offers one explanation. The second deals with the Wheeler–Feynman (1945) absorber theory which depends on the causal existence of advanced and retarded waves, and which needs to be reconciled with current cosmologies.

The hypothesis is not directly testable, and no experiment can as yet be undertaken to falsify it. Stated otherwise, there are no known probability distributions against which it may be tested. If we follow this path, we are in some sense abandoning the paradigm of the Copenhagen interpretation[1] of quantum mechanics, in which only states with calculable probabilities will be considered; others are discarded as of no practical use (the "shut up and calculate" approach sometimes invoked in modern physics). This paradigm prevents us from questioning certain underlying, untestable foundations upon which our science may be based. This article is not a suitable forum

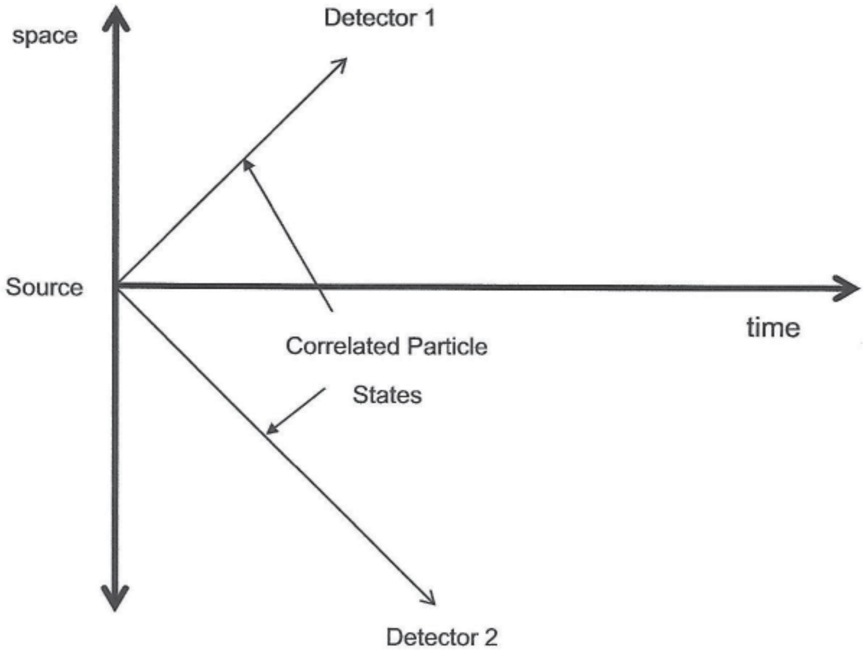


**Figure 1. Space–time diagram of two entangled particles departing from a common source and moving apart in opposite directions in space and forward in time.**

to discuss the merits or demerits of such an approach. Suffice it to say that we choose to go beyond the Copenhagen interpretation. In place of testing against calculable probabilities we will test against Occam's razor,[2] which is a method of ordering the a priori likelihood of various states, which may have no calculable probability distributions, and choosing to explore those which are most likely.

As a thought experiment and a test bed for the hypothesis, we will invoke Bell's theorem (Bell 1964) and the Aspect experiments (Aspect, Dalibard, & Roger 1982, Aspect, Grangier, & Roger 1982). Bell's theorem shows that under some conditions either quantum mechanical predictions fail or causality is nonlocal. The Aspect experiment tested the theorem in a situation in which entangled photons of correlated polarization are generated and measured.

Figure 1 shows a diagrammatic explanation of the experiment. We will then deal with the absorber theory (Wheeler & Feynman 1945) as a requirement for the validity of the first hypothesis, and show where it needs modification which may allow it to fit our current cosmological models.

## Alternatives for Nonlocal Causality

A number of researchers have discussed time reversal of cause and effect, sometimes dubbed as retrocausation, as a working hypothesis (e.g., Costa de Beauregarde 1977, Lear 2012, Sheehan 2006). Alternative approaches deal with the concept of retarded and advanced wave (e.g., Moffat 1998, Wheeler & Feynman 1945) wherein retrocausation is implied, but is not an emphasis. We first discuss six alternative sub-hypotheses for nonlocal causality. We will compare them under the guidance of Occam's razor.

1. The first alternative, perhaps the most widely used, is that entangled particles form a single quantum state, and will respond to a measurement as any state does, by yielding a sub-state out of the superposition. This is pure, pragmatic Copenhagen interpretation. The cause is the measurement and the effect is the collapse of the wave function, or reduction of state. But the relationship between a measurement and a wave function collapse is purely formal and not physical.

Niels Bohr never wrote about wave function collapse. Heisenberg called it the reduction of a wave function to a new state representing the change in knowledge of the state due to the outcome of a measurement. So we might assume that the Copenhagen interpretation considers a measurement as a probe of a system, and the wave function collapse as the recording of the results of that probe. We assume neither of these need be subject to conscious awareness. These are certainly causally connected, and the causality is forward in time if we make a distinction between the measurement process and the recording process.

In the case of entanglement of two polarized particles, the probe is the insertion of a polarizer and the recording is the registry of an electromagnetic signal. The measurement of an event at one pole of the system is not contiguous with the recording of the event at the other pole. This is so in the sense that the measurement and recording do not have a direct path between them in space and time within their respective light cones. Contiguity is not established until the two data streams are brought together in the lab and correlations are established. In this sense, the state is not reduced until the correlations are recorded. It is this disruption in contiguity that led to Einstein's complaint of spooky action at a distance, and led to the coinage of the term *nonlocality*.

Traditional causality is defined as a sequence of interdependent events that are contiguous in time and space, and there is an urgency to retain this tradition.

2. A second alternative is that causality acts outside of the realm of spacetime. One might argue that causality as a physics principle is

independent of, or transcends, the relationships of occurrence of events in space and time. Then its true structure remains to be discovered, as does its mode of interaction with spacetime.

3. A third alternative holds that causality is not a natural law at all, but is an artifact of human experience. It is an outgrowth of a larger reality, useful only in describing our experience of spacetime. As a sort of restatement of the second alternative, this explanation gives no clue to the underlying nature of the structure of causality within spacetime.

4. If there are hidden causal interactions between the two detectors and the source, such as David Bohm's pilot wave[3] which guides particulate entities, their responses may be guided as specified by quantum mechanics. The tentative fourth alternative arising from this is that if there is a hidden transmission of causal interaction from one detector to the other it must be "superluminal" (faster than light speed). In Figure 1, this would correspond to an arrow pointing directly from one detector to the other. Tachyons, for example, are hypothetical imaginary particles with speed faster than light, never slower, and would be capable of transmitting superluminal signals.

In a variant of his experiment, Alain Aspect (Aspect, Dalibard, & Roger 1982) modified his apparatus so that the polarization of the first detector was set after the photons had left the source. The polarization correlations of the second detector with the first detector were realized before the decisions were made on the polarization state of the first. It follows that any spacetime causal connection appears to have been time-reversed. The polarization change was accomplished in a pseudo-random fashion. The Aspect experiment left no signature for the presence of a transmitting particle. A tachyon, if present, could not show itself in Lorentzian spacetime.

5. A fifth alternative has causality acting in a relativistic Lorentz transformed frame of reference which is necessarily not homomorphic with the observer's frame. Such a relative frame of reference would result in certain simultaneous events (being spacelike events) becoming separated in time (becoming timelike events), but would still cause the appearance of superluminal transmission as in the fourth hypothesis.

6. The sixth and final alternative is also a Lorentz invariant transformation, as in the fifth. But it is an improper Lorentz transformation, with the time element of the transformation matrix reversed in sign. In this, causality as well as dynamics may be time-reversed, so that the cause follows the effect in time.

## Occam's Razor and Causal Time Reversal

Occam's Razor holds that the simplest explanation for a proposition is the most probable, because the simplest has the least number of assumptions to which a prior probability must be assigned.

We take as a working principle that things or concepts that are less easy to imagine, visualize, or explain, in terms of the illustrative power of the verbal or graphical description, will have lower prior probability of real existence because of the potentially larger numbers of modes of realization of such.

Among the alternatives for nonlocal causality presented in the previous section, **Alternatives For Nonlocal Causality**, numbers one through three show no answers at all to the relationship of causality to spacetime. If we suppose that this relationship holds, these three are unsatisfactory. Because they lack direct explanatory power, they potentially have a complexity of multiple paths to explanation, and have a low probability of providing an explanation. In and of itself, the fourth alternative appears to violate special relativity because it is superluminal signaling and attempts to impose the causal relationship within the observer frame of reference. The fifth alternative also results in superluminal transmission of causal action. There is no Lorentz transformation that can change a spacelike event into a timelike event. Such transformed reference frames have the shortcoming that there are still no apparent signal carriers to provide contiguity between cause and effect. The probability of causal connectivity existing in such reference frames is low.

This leaves the sixth alternative as the simplest and most rational. In the time-reversal mode, the photons or other particles moving between the source and the detectors may act as signaling paths.

Figure 1 shows arrows pointing away from the source, indicating a timewise forward motion of the particles, and implying a causal link forward in time. If one of the arrows pointed back toward the source, this could be taken as a causal link starting at the detector, which more or less randomly determines a single polarization state, which then determines the source in that state in a retrocausal fashion. The unique state thus assumed by the source will then cause the measurement at the other detector to be suitably correlated. This is time reversal of cause and effect, or advance wave causality.

## Dynamic and Causal Time Reversal: Symmetry and Cosmology

Cause and effect are multipolar. The poles are sequences of events. As a working hypothesis, we suppose that poles are causally connected if their dynamics are correlated with each other in time and space. The dynamics of one such sequence is correlated with and dependent upon the dynamics of another. Such correlation is always subject to statistical discovery, although in many instances the statistics are so strong as to be counted as certainty. And in others, the statistics are clearly absent.

In this view of causality, we suppose that the information content of a sequence of events is causal, and the dynamics are effectual. The action of the causal sequence is driven by information that is correlated with that action. In contrast, insofar as the action of a sequence is correlated only with action in another sequence, that action is effectual.

In the abstract, information is the resolution of uncertainty. In a classic paper Claude Shannon (1949) quantified information in terms of a weighted sum of bits now called the Shannon entropy:

$$H = -\Sigma_i p_i \log_2(p_i)$$

The $p_i$ are the probabilities of various outcomes of a sequence of events which for our purposes is a causal pole. For example, in the Shannon formalism the sequence was the transmission and reception of a string of bits in a communication channel.

Without an observation, the number of possible outcomes is manifold. If an observation is made, the number of possible outcomes is always reduced, but not always to a single outcome. The result of an observation is a reduction in the Shannon entropy. The dynamical entropy, which is the negative of the Shannon entropy, is increased.

In our second-law temporal universe, dynamical entropy in a closed system tends to increase over time. Informational entropy decreases, meaning a system that was initially highly causal becomes less causal. The second law dictates the time sequencing of cause before effect.

Some examples will illustrate. Suppose a billiards player wields a cue. His intention supplies information to the initiating action of the cue striking the ball, resulting in effectual action of other billiards on the table. That is a simple bipolar causal chain in which cause and effect are well-defined and separated. The array of struck balls contains information, but the information content of the player and his cue is overwhelming. The observation of cause and effect is in the correlation of the motion of the billiards with the use of the cue. In all other cases also, correlation of dynamical action is the observable.

Suppose a number of individuals are given boxes of identical kitchen blender parts, then divided into two groups, one of which is given written instructions on how to assemble and use the blender while the other group is told only to use the blender to perform a food preparation. The use of instructions is causal, but the only discovery of a causal relationship comes from the correlation of success with the use of the blender with the use of instructions. There is no other external acting mechanism (such as a cue) driving the success rate.

In an arm wrestling contest (or a ball game) the wills are causal, but physiology is effectual, and the result is a balance of the two.

In agriculture, weather factors may be highly correlated with crop yield, but this is a classic case of confounding cause and effect. Ultimate causation may lie with solar energy.

Classical physics adds two other principles to this idea of information and correlation. Classically, a cause must precede its effect, and a causal chain must have contiguous elements throughout its spacetime domain.

The symmetry of dynamic time reversal is well-known in field theory. Under the time reversal operator T, the dynamical time variable *t* changes sign but the state vector does not change. If a state is symmetric under dynamical time reversal, it is reasonable to assume that it must also be symmetric under causal time reversal. That is, the operator T not only changes the sign of *t* but it also changes the polarity of cause and effect.

Radiation emission events are causal insofar as they involve a state transition invoked by information reduction. Radiation absorption is causal for the same reason. The information transfer in the absorption process may be seen as the basis for advance wave causality.

There are broadly three areas that challenge the symmetry of time reversal. These are T-violation processes, second law processes, and what we know about cosmology.

Mesonic decay processes have indicated the presence of CP-violation, and hence T-violation, for many years. Over the last decade or so, higher energy B meson decay processes have confirmed it.[4] T-invariance alone is not enough to guarantee causal time reversal in every case. But all these processes are invariant under CPT (Charge conjugation, Parity transformation, and Time reversal), which includes charge conjugation and parity, or coordinate inversion. CPT invariance may be sufficient to exchange the polarity of cause and effect.

Causal polarity reversal is an attractive concept in part because it maintains contiguity through particle paths, and the process remains Lorentz invariant. The formalism of the Feynman diagram is widely used as a picture of a particle as an antiparticle traveling backwards in time and space. They are mathematically equivalent under CPT, and potentially each carries a causal signal.

Another challenge is the possibility that retrocausation is inconsistent with the second law. If retrocausation emerges macroscopically, the consequence could be at least a limited violation of entropy increase within closed systems. Note first that microscopic causality and microscopic dynamics are both time reversible, and we can claim they both obey the CPT invariance and Lorentzian invariance. Note, however, that microscopic causality and dynamics must translate to macroscopic causality and dynamics. If the second law only governs forward causality of macroscopic dynamics, we can provide a basis for it as a principle of cosmological thermodynamics, and not as a quantum principle. The underlying principle is simply the well-known ad hoc statement that thermodynamic time proceeds in the direction of maximum likelihood. In the work that follows, then, we will need to also exclude cosmological electrodynamics from second law effects.

A final challenge is the apparent inconsistency of the Wheeler–Feynman absorber theory (1945) with most currently accepted cosmological models. Absorber theory strongly supports the role of advance causal electromagnetic waves in the structure of the cosmos. The attractive feature of absorber theory is that it eliminates the apparent lack of radiative damping of an accelerated electron emitting a photon during a state transition. Wheeler and Feynman (1945) proposed, and Hoyle and Narlikar (1995:126) found, that the absorber theory requires perfect (future) absorption of retarded waves and imperfect (past) absorption of advanced waves in the cosmological time scale. Hoyle and Narlikar (1995:139) also found that the imperfect past absorption requirement is inconsistent with all the useful cosmologies. Were it not for these inconsistencies, absorber theory would not be a challenge to advance wave causality.

## Future Absorption

In Wheeler–Feynman absorber theory the advanced and retarded fields contribute equally to the total field. In the nomenclature of Hoyle and Narlikar (1995:119), the field acting on an emitting charge (a) is the sum of advanced and retarded fields of all other absorbing charges (b):

$$F_{\text{total}}^{(a)} = \Sigma_{b \neq a} \frac{1}{2} [F^{(b)\text{ret}} + F^{(b)adv}]$$

We noted above that in the view of Hoyle and Narlikar (1995:139) perfect (future) absorption of retarded waves is not possible in the Wheeler–Feynman theory for most of the useful cosmologies. They proposed quasi–

steady-state cosmologies as a possible remedy, but these have suffered loss of credibility over time due to inconsistency with cosmological data (Wright 2015) and the resulting complexity of explaining such inconsistency. They also showed, as did Wheeler and Feynman, that perfect future absorption is a requirement if absorber theory is to alleviate the dynamical inconsistencies arising from photon emission by accelerated electrons. Hoyle and Narlikar (1995:125–126) showed the closed Friedmann cosmology as supporting both perfect past and future absorption. They found other closed cosmologies that support perfect future absorption, but allow only imperfect past absorption.

Perfect future absorption in a closed universe is apparently achievable because radiation may recirculate throughout the enclosure until it is captured. Perfect future absorption may not occur in an open, expanding universe if the future absorber density is too small to capture the retarded radiation.

Our current cosmological database strongly supports the existence of a cosmology that is open, flat, and expanding. The Hoyle–Narlikar analysis as just discussed determined that, based on current models of the density of matter in the universe, there are not enough future absorbers to complete the needed absorption. But absorber theory requires perfect future absorption. So if we are to proceed along these lines, we will need to find other cosmological alternatives for future absorption.

We have recently completed a study that provides such an alternative (Lear 2016). Given the dearth of real future absorbers, we suppose the presence of virtual electromagnetic pairs emergent throughout spacetime within the constraints of the Heisenberg uncertainty principle. Such virtual absorbers appear often enough to capture all the primal radiation from the big bang as well as subsequent emissions. Such capture will result in absorption and immediate re-emission of both retarded and advance waves.

Due to relativistic cosmic expansion, some regions of spacetime will come to recede from one another with speeds approaching and greater than that of light. Such regions lose causal contact with each other, and their interface constitutes a light horizon beyond which absorption of retarded waves no longer would result in advance waves being returned to the emitter. Absorption at the light horizon completes perfect absorption, resulting in advance waves returning to the emitter and retarded waves receding into a region causally disconnected from the emitter. By this means, the requirements of Wheeler–Feynman absorber theory are satisfied.

## Discussion

The literature on causality in physics contains many ramifications of definition, concept, and philosophy of cause and effect. In this work, for simplicity's sake, we have adhered to a basic concept, founded primarily in the classical definitions. We have used three classical principles, and we have proposed modifications to those principles.

The first is that a cause precedes its effect in time. This principle can be held to in special and general relativity as well. Another way of stating it is that an effect occurs in the forward light cone of the cause.

The second principle is the space and time contiguity of elements in a cause-and-effect chain. An outcome of this is that in processes involving action-at-a-distance, there are always conceptual carriers of force or other information connecting the elements of a chain.

Thirdly we used an ad hoc principle that altering or manipulating a cause will change an effect, but that effects are not subject to manipulation other than through causation.

To be physically viable, each of these principles should be testable. Their application to classical and relativistic dynamics is fairly straightforward. Their application in quantum field theory is perhaps somewhat murky, and we have explored this.

Among ramifications we have bypassed or ignored, for example, are the dependence of the simultaneity of events on the motion of rest frames in special relativity. Also, there are so-called "non-causal" dynamics such as Newton's first law of inertial motion, which do not appear to require causality to be enforced. We have bypassed discussion of causal paradoxes, leaving those to the mercy of probabilistic interpretation.

Within these constraints, the one we have proposed abandoning is the first of the three principles, that of forward causality. As a principal justification for this, we have shown that the simplest explanation of quantum entanglement lies with attributing causal action to advance waves—in other words, time reversal of cause and effect.

We addressed the symmetry breaking of causality in time by invoking the underlying principle of the second law, suggesting that thermodynamic time flow is governed by the outcome of greatest probability. This divorces thermodynamic time flow from the causal time symmetry occurring on the quantum level.

As a secondary justification for advance wave causality, we have turned to Wheeler–Feynman absorber theory, which requires a mixture of advanced and retarded waves to provide radiative damping for electromagnetic emissions from atoms. In doing so we have accepted the necessity for radiative damping forces acting externally on accelerating electrons emitting radiation in quantum transitions. Such damping forces are apparent, for example, in bremsstrahlung radiation at the quantum level, and in any macroscopic process involving acceleration of charge.

The difficulties with absorber theory are mainly cosmological. We have addressed this in a previous paper (Lear 2016). There is a symmetry breaking of cosmological time, which we have addressed through thermodynamics. Also in an open Friedmann cosmology, comparable to what we know currently about the standard cosmology, there is a lack of future real absorbers to match early emissions. We have alleviated this by showing the possibility of future virtual absorbers that may fully capture all primal radiation before and when it reaches the light horizon. Future absorbers are potentially plentiful in the form of electron positron pairs, with lifetimes limited by the Heisenberg uncertainty principle, but sufficient to perform absorption and re-emission of photons.

## Notes

1 The Copenhagen interpretation of quantum mechanics was formulated by Niels Bohr and colleagues working in the early 1900s in Denmark. It is very pragmatic. Very briefly, the interpretation says that quantum mechanics cannot describe the nature of reality beyond what the axiomatic theory is capable of predicting, and that any interpretation beyond that theory is without substance and is of no usefulness to physical science. Most textbooks on quantum mechanics are good resources for study.

2 William of Ockham (aka Occam) was an early fourteenth-century English Franciscan friar and a scholastic philosopher, who is believed to have been born in Ockham, a small village in Surrey. He was a major figure in scientific and logical thinking in medieval times. He is best known for the logical principal that bears his name. There is an abundance of online reference to the application of his principle of simplest hypothesis being the most likely to be true.

3 Bohm's pilot wave hypothesis holds that particles are substantial objects following well-defined trajectories in space and time, and that these trajectories are guided according to the amplitudes of the system state vector. Most modern quantum textbooks will have a discussion of the pilot wave hypothesis.

4 There are numerous online references to B meson decay CP violation. A recent survey by Roland Waldi, "B meson decays and CP (and T) violation" (14 January 2013), from the Proceedings of the 32nd International Symposium on Physics in Collision (PIC) conference, 12–15 September 2012, Štrbské Pleso, Slovakia, may be found at arXiv:1301.2509v2 [hep-ex]

## Acknowledgments

The author gratefully acknowledges the help of Farhang Amiri, Daniel Schroeder, and Brad Carrol of Weber State University, and James Glass at the University of Eastern Washington, who provided comment and critique in preparing this paper.

## References Cited

Aspect, A., Dalibard, J., & Roger, G. (1982). Experimental test of Bell's inequalities using time-varying analyzers. *Physical Review Letters, 49*(25):1804–1807.

Aspect, A., Grangier, P., & Roger, G. (1982). Experimental realization of Einstein-Podolsky-Rosen-Bohm *Gedankenexperiment*: A new violation of Bell's inequalities. *Physical Review Letters, 49*(2):91–94.

Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics, 1*(3):195–200.

Costa de Beauregard, O. (1977). Time symmetry and the Einstein paradox. *Il Nuovo Cimento, 42B*(1):41–64.

Hoyle, F., & Narlikar, J. V. (1995). Cosmology and action-at-a-distance electrodynamics. *Reviews of Modern Physics, 67*(1):113–155.

Lear, C. W. (2012). The Bell inequality and nonlocal causality. *Journal of Scientific Exploration, 26*(4):767–780.

Lear, C. W. (2016). Wheeler–Feynman Absorbers on the Light Horizon. November. Arxiv.org 1611.05331

Moffat, J. W. (1998). Quantum measurements, nonlocality, and the arrow of time. https://www.researchgate.net/publication/1976163_Quantum_Measurements_Nonlocality_and_the_Arrow_of_Time

Shannon, C. E. (1949). *The Mathematical Theory of Communication.* Urbana, IL: University of Illinois Press.

Sheehan, D. (Editor) (2006). Frontiers of Time: Retrocausation—Experiment and Theory. In *Record of a Symposium Held by the Pacific Division of the American Association for the Advancement of Science*, San Diego, California, 20–22 June 2006, New York: AIP Press.

Wheeler, J. A., & Feynman, R. P. (1945). Interaction with the absorber as the mechanism of radiation. *Reviews of Modern Physics, 17*(2–3):157–181.

Wright, E. L. (2015). Errors in the Steady State and Quasi-SS Model. http://www.astro.ucla.edu/~wright/stdystat.htm