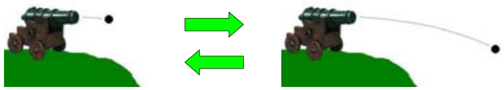
Wheeler/Feynman Absorber Theory and the Radiation Arrow of Time

Kevin Engel, Peter Kernan

Case Western Reserve University Department of Physics

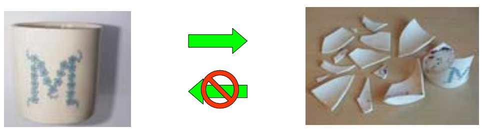
What is the Arrow of Time?

The fundamental laws of physics are time symmetric. The same set of processes which happen in the forward time direction can also happen in the backward direction.



In the above illustration, Newton's second law can be used to find the trajectory of the cannon ball regardless of whether time is run forward or backward.

However, playing a film backwards quickly reveals that everyday life is clearly asymmetric. As shown below a cup, once shattered, will not spontaneously reform.

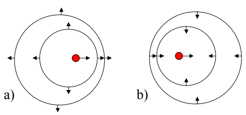


This asymmetry and others point out a directionality of time not found in our theories and are thus labeled 'the arrow of time.'

The Radiation Arrow of Time

The radiation arrow reflects the observation that waves always propagate outward from a source. Whether water waves, sound waves, or electromagnetic waves, all radiation exhibits this asymmetric behavior.

As usual, though, the theory is symmetric. In electrodynamics, Maxwell's equations allow for two different forms of radiation: retarded and advanced waves.

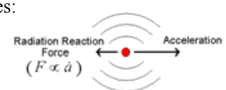


a) Retarded radiation – waves propagate forward through time

b) Advanced radiation – waves propagate backward through time. Seen from our perspective, they appear to collapse on the source just before it is accelerated

Because advanced waves allow the future to affect the past, most EM textbooks dismiss the advanced solutions with an appeal to the unproven principle of causality. With this assumption, the classical equation of motion for a charged particle becomes:

$$F_j = \sum_{k \neq j} F_{ret} - F_{rad} \qquad (1)$$



where the force on the jth particle is given by the sum of the forces produced by the *retarded* fields of all the other particles in the universe minus the radiation reaction force. The radiation reaction force is a consequence of energy radiating away from the particle.

The Absorber Theory of Radiation

In 1945, Wheeler and Feynman introduced their absorber theory. The two men proposed a time symmetric version of electrodynamics in which moving charges emit both retarded and advanced radiation. Under this theory, the new equation of motion becomes:

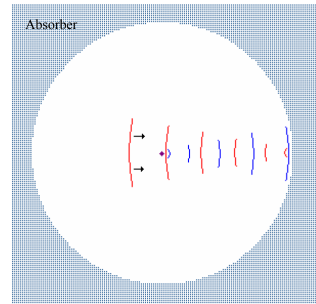
$$F_j = \sum_{k \neq j} \left(\tfrac{1}{2} F_{ret} + \tfrac{1}{2} F_{adv}\right) \qquad (2)$$

Next, Wheeler and Feynman made the assumption that the universe as a whole is a perfect absorber of electromagnetic radiation. This absorber condition is vital to the theory, and can be represented in equation form:

$$\sum_k (F_{ret} - F_{adv}) = 0 \quad \text{(everywhere)} \qquad (3)$$

By adding Eq. (2) to Eq. (3), Wheeler and Feynman were able to recast their equation of motion into a very familiar form:

$$F_j = \sum_{k \neq j} F_{ret} - F_{rad} \qquad (4)$$



Retarded waves (blue) cause the absorber to emit advanced waves (red). Near the particle, the advanced waves appear to reinforce the retarded ones.

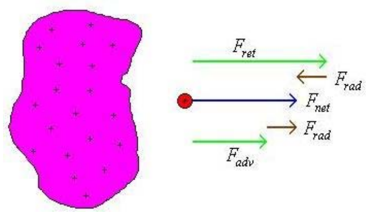
This is the surprising conclusion of the absorber theory. Although radiation in this theory is half retarded, half advanced, it can actually *appear* to be fully retarded, agreeing exactly with the classical result (Eq. 1). The figure above illustrates how interactions with the absorber forward and backward in time make this result possible.

However, Wheeler and Feynman also realized that by subtracting Eq. (3) from (2), an alternate equation of motion can be found where radiation appears entirely advanced:

$$F_j = \sum_{k \neq j} F_{adv} + F_{rad} \qquad (5)$$

In this equation, though, the radiation reaction is positive, corresponding both to an energy gain and a force which amplifies the acceleration. Because this kind of behavior has never been observed, Wheeler and Feynman decided that Eq. (5) is not valid, thus destroying the time symmetry of their theory. They conclude that thermodynamic processes in the absorber are responsible for the radiation arrow of time.

A Reinterpretation



An accelerating charged particle feels the same net force whether calculated from retarded forces (upper) or advanced ones (lower)

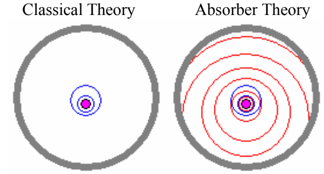
Although the structure of their theory is sound, Wheeler and Feynman erred in their conclusions. A correct interpretation of the absorber theory maintains its time symmetry and completely eliminates the radiation arrow of time. The key point is that the two equations of motion spring from the same source. If the assumptions made in Eqs. (2) and (3) are correct, then both Eq. (4) and Eq. (5) must be true. Nature does not select one or the other, it is forced to obey both. In a perfectly absorbing, time symmetric electrodynamics, *radiation can be represented as either fully retarded with a negative radiation reaction or fully advanced with a positive radiation reaction.* The illustration to the left demonstrates how the two different representations yield the same net force.

Unlike before, this reinterpretation is completely time symmetric. In this theory, the radiation arrow of time is an illusion, nothing more than a matter of perspective.

Experimental Verification

This reinterpretation can be tested experimentally, for unlike Wheeler and Feynman's original theory, it predicts that Eq. (5) is just as valid as Eq. (4). One possible experiment is shown to the right.

A small charged object is accelerated from the middle of a spherical conducting shell. If radiation is entirely retarded, then both before and for a brief time *after* the acceleration begins, the surface charge on the sphere will remain uniform. If instead, Eq. (5) is correct, upon acceleration, the particle will emit advanced waves backward in time, and the surface charge will begin to respond *before* the acceleration. We hope that this difference will be measurable, and are currently attempting to calculate the theoretical surface charge for the two different scenarios.



Radiation emitted by particle/conductor system at $t \approx 0$ for two different versions of electrodynamics

References

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