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On recent experiments to detect advanced radiation

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Abstract. Inconsistencies in the usual interpretation of the absorber theory of radiation are exposed which invalidate an experiment proposed recently by Heron and Pegg. An earlier experiment by Partridge necessarily gave a null result owing to absorption on the far side of the Earth of any advanced radiation which may have been present.

1. Introduction

There have been a number (Csonka 1969, Partridge 1973 and Heron and Pegg 1974) of proposals and experiments in recent years aimed at the detection of advanced electromagnetic radiation. That is, an electromagnetic disturbance received at a detector *before* a distant radiating source is stimulated. Such a bizarre possibility has always been allowed within the framework of the laws of electrodynamics, which are symmetric under time reversal. Indeed, it is possible to recast Maxwell–Lorentz theory in a form in which both advanced and retarded disturbances are produced equally by a radiating source, so that the electrodynamic aspects of radiation are manifestly time-symmetric. The apparent predominance of the retarded radiation in the real world may then be attributed to the properties of a distant absorbing medium. In this form, the theory of electrodynamics is called the *absorber theory*, and was developed initially by Wheeler and Feynman (1945). The main result of the absorber theory is that it is in all respects identical to the conventional formulation of Maxwell–Lorentz theory (with *ad hoc* retarded boundary conditions) for all systems within an opaque enclosure, ie, systems for which the distant medium absorbs all radiation completely. (There is one exception to this result, concerning the absence of divergent particle self-energies in the classical version of the absorber theory, such divergences being inescapable in the conventional formulation.)

For systems which are not confined to an opaque enclosure the situation is less clear, but the possibility apparently exists for a stimulated source to give rise to *both* retarded and advanced disturbances in some ratio. In view of the distinct possibility that the Earth is not situated within an opaque region of the universe, several authors have suggested experiments to detect the advanced component of the radiation which may then exist according to the absorber formulation, and in one case (Partridge 1973) an experiment has actually been carried out.

Some confusion exists in the literature over the terminology 'advanced radiation' and the interpretation of its physical significance. In part, this is due to the existence of *two* distinct absorber theories, the original being due to Wheeler and Feynman, which attempts to recover the predominance of retarded radiation from the thermodynamic properties of the absorbing medium, and the other, developed at a later date by various cosmologists (Hogarth 1962), particularly Hoyle and Narlikar (1963), which attempts to achieve the same end using cosmological arguments. It is the latter theory to which the large majority of commentators appear to subscribe.

The purpose of this paper is to clarify and distinguish between these two theories, and their relationship to the various suggested experiments, and to advance reasons in support of the former, less familiar, theory.

2. Wheeler–Feynman absorber theory

Only a brief discussion will be given here, because the details have been repeated many times elsewhere (Hoyle and Narlikar 1963, Davies 1974, chap 5). The basic principle is the assertion that the electromagnetic field of a particle j, abbreviated to $F^{(j)}$ for convenience, is a time-symmetric mixture of advanced and retarded components: $\frac{1}{2}F^{(j)}_{\text{adv}}+\frac{1}{2}F^{(j)}_{\text{ret}}$, in obvious notation. The total field of a collection of charged particles acting on a particle i is then

$$\sum_{j\neq i}\left(\tfrac{1}{2}F^{(j)}_{\text{adv}}+\tfrac{1}{2}F^{(j)}_{\text{ret}}\right). \tag{1}$$

Note that there is no self-action in expression (1), $F^{(i)}$ being absent. Of course, the motions (and attendant fields) of the set of particles may not all be specified independently because of their mutual interaction. However, Wheeler and Feynman managed to find a number of self-consistent motions of the set of particles with particularly simple properties. For example, the net field acting on a particle i by the combined interference of the fields of the set j will be equivalent to

$$\sum_{j\neq i} F^{(j)}_{\text{ret}}+\tfrac{1}{2}\left(F^{(i)}_{\text{ret}}-F^{(i)}_{\text{adv}}\right) \tag{2}$$

if the motions of the set j are arranged to correspond to a completely opaque enclosure ie all radiation incident on the interior of the enclosure is unable to penetrate to the exterior, being absorbed instead (hence the name 'absorber theory'). Expression (2) is the usual retarded form for the fields acting on a particle i, including the finite part of the self-action responsible for the radiation reaction force.

Another self-consistent set of motions may be obtained by time-reversing the first, so that the enclosure is still opaque, but gives rise to advanced radiation only

$$\sum_{j\neq i} F^{(j)}_{\text{adv}}-\tfrac{1}{2}\left(F^{(i)}_{\text{ret}}-F^{(i)}_{\text{adv}}\right). \tag{3}$$

Notice that the sign of the radiation damping force is reversed, corresponding to anti-damping of an accelerated charged particle i by the incoming (advanced) radiation.

The two solutions (2) and (3) may be illustrated schematically by figures 1 and 2.

In figure 1, (b being the time-reverse of a), the vertical lines represent world lines of charged particles, the collection on the right being the set labelled by j while the single one on the left is the accelerated charged particle of interest, i. The heavy portions of the world lines denote the excitation of the particle with the energy of the radiation. The oblique lines are the null cones, showing the passage of radiation between i and j. It is a matter of indifference which of (a) or (b) is associated with (2) or (3) because until now there has been complete time symmetry. However, the word 'retarded' is normally used

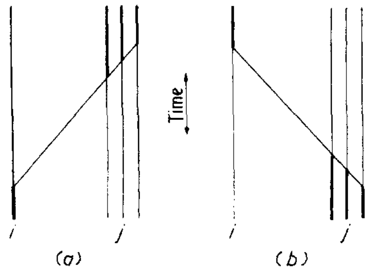

Figure 1.

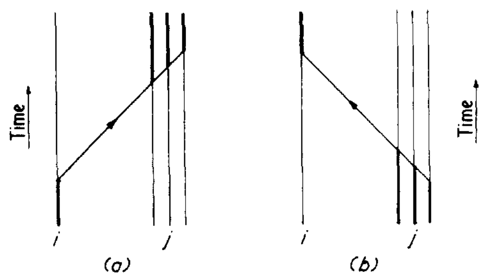

Figure 2.

to mean 'along the *future* null cone', so that appeal must be made to a non-electromagnetic physical mechanism to supply an asymmetry in time against which we may distinguish past and future null cones. Discussions of temporal asymmetry usually centre on thermodynamics, so if we take entropy to increase up the page, figure 1 may be redrawn as in figure 2, which has the obvious interpretation that (*a*) corresponds to retarded radiation leaving *i* and being absorbed in the distant collection *j* while (*b*) corresponds to advanced radiation from *i* leaving the set *j* and collapsing onto *i* at the moment of acceleration.

We now have a ready-made reason why (apparently) (*a*) only is observed, and not (*b*). The thermodynamic tendency for entropy to increase with positive time in figure 2 precludes the cooperative de-excitation of large numbers of particles *j* at just the right moment to bring about a coherent converging wave onto *i*. Such a large fluctuation is exceedingly improbable on statistical mechanical grounds.

3. Hogarth–Hoyle–Narlikar absorber theory

The thermodynamic explanation of the non-existence of advanced radiation has not received support from the majority of subscribers to the absorber theory. Instead, the cosmological expansion is usually invoked as the asymmetric process which allows retarded radiation only. Arguing on the grounds that the mean free path of an average photon is comparable with the Hubble radius, subsequent authors have stressed that account must be taken of the gross motion of the absorbing material due to the expansion of the universe. When this is done, the physical condition of the absorbing matter (eg density, temperature) will generally be different along the two null cones, as well as the fact that a cosmological frequency shift of the radiation will take place. It may then happen that the self-consistent set of motions corresponding to an opaque enclosure are only possible along *one* of the two null cones. If this happens to be the *future* null cone, but not the past, then the existence of retarded radiation only is explained. In practice, only the steady-state theory satisfies this happy condition. Unfortunately, the C-field cosmology of Hoyle and Narlikar, which provides the only theoretical justification for the steady-state theory, does not permit fully retarded radiation (Davies 1972a).

However, a simple analysis (Davies 1972a) of the absorptive properties of homogeneous, isotropic, matter-conserving cosmologies reveals that the future null cone is opaque as a result of inverse bremsstrahlung absorption by free ions if the scale factor $R(t)$ in the Robertson–Walker metric behaves like

$$R(t) \to t^n \qquad \text{as } t \to \infty,\ n \leqslant 2/5.$$

It so happens that total ionic recombination will occur for $n \leqslant 1/2$, so that all ever-expanding models of this variety are future-transparent, unless $n \leqslant 1/3$ when absorption by discrete objects is complete. Recontracting models, such as the $k = +1$ closed Friedmann model, are opaque.

Future-opaque models such as these have been rejected by many authors as candidates for the absorber theory on the grounds that their past null cones are also opaque. This is no problem if the thermodynamic properties of the absorber are invoked as before. However, the status of thermodynamics in the Hogarth–Hoyle–Narlikar theory is very obscure, and when the opacity of the past null cone is discussed, no mention is made of the fact that the situation described by figure 2(*b*) is exceedingly improbable on statistical mechanical grounds. The justification for neglecting thermodynamics made by Hoyle and Narlikar was based on the questionable premise that the second law of thermodynamics might follow from the retarded nature of radiation rather than the other way around, as used in the Wheeler–Feynman interpretation. This supposition is totally unconvincing, if only because the H theorem of Boltzmann is derived on the assumption of the instantaneous interaction of electrically neutral particles, and has nothing whatever to do with electrodynamics or retardation. It is possible to argue at a more profound level for the self-consistency of retarded radiation and entropy increase (Davies 1974, p 198), but at best the argument is circular, for the future absorption is necessary to produce retarded radiation, which in turn is supposed to lead to the entropy increase which is itself a prerequisite for the absorption to take place. The attempt by Hoyle and Narlikar to break out of this circular argument is not successful. In their 1963 paper they attempt to derive the retarded radiation without appealling to thermodynamic absorptive processes (such as inverse bremsstrahlung) at all. All that is considered is Thomson scattering by free particles, which of course does not actually represent absorption at all. It has never been demonstrated that scattering alone is sufficient for application of the absorber theory.

In addition to this, severe ambiguities arise in some models (such as those with incomplete absorption) when absorption (in the sense of figure 2) is supposed to occur both in the past and future at the same time. For it is supposed in this treatment that a piece of absorbing material which lies on the future null cone of one luminous source and the past null cone of another will simultaneously 'absorb' in both directions of time (see figure 3). It is not at all clear what meaning to attach to a system the entropy of which is supposed to be at the same time increasing and decreasing.

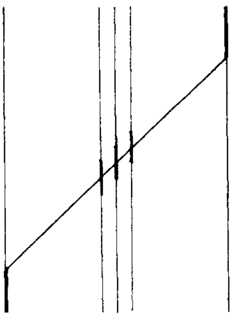

Figure 3.

4. Incomplete absorption

In view of the fact that the real universe is probably more or less transparent on the future null cone (eg Einstein–de Sitter model), the question is raised of what pattern of radiation fields would be expected in an incompletely absorbing system.

In their original paper, Wheeler and Feynman proposed two self-consistent solutions for this circumstance. These solutions will now be described using a simple model, shown in figure 4, which consists of a single charged particle *i* placed in front of a completely absorbing screeen in a (Minkowski) space which is otherwise empty except for another charged test particle *a*.

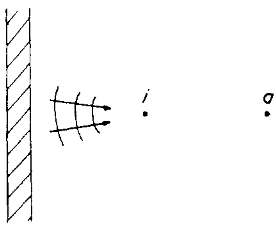

Figure 4.

Particle *i* is given a non-electromagnetic acceleration. The particles in the direction of the screen will then receive the fully retarded field of *i* by the usual mechanism of absorber response operating in that direction. However, there are other fields present also due to the absence of absorbing material to the right of *i*.

In the first solution envisaged by Wheeler and Feynman, a fully advanced field sets into motion the particles on the inside (ie right) face of the screen *before* *i* is accelerated. This fully advanced field consists of the $\frac{1}{2}$ advanced primary field of *i* plus the retarded response of the screen. The latter response field also cancels the $\frac{1}{2}$ retarded primary field of *i* in the direction remote from the screen, and in addition reduces the radiative damping force on *i*. Moreover, the advanced field of the screen in response to the usual retarded field of *i* also cancels the $\frac{1}{2}$ advanced field of *i*, so that neither advanced nor retarded fields propagate to the right of *i* to be detected by *a*.

In the second solution, *a* does detect fields from *i*—in fact, the fully retarded field of *i*. This comes about in the following way. The $\frac{1}{2}$ advanced field of *i* coming in from left hand infinity strikes the far (left) side of the absorbing screen (see figure 5) where it is

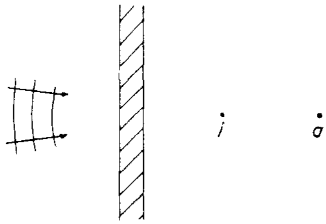

Figure 5.

absorbed. The absorbing particles give rise to $\frac{1}{2}$ advanced + $\frac{1}{2}$ retarded response fields, which make up the field to the left of the screen to fully advanced, and just cancel the $\frac{1}{2}$ advanced field of i in the body of the absorbing screen and to the left of i. To the right of i however, the $\frac{1}{2}$ retarded response field makes up the $\frac{1}{2}$ retarded field from i to fully retarded, so that the resultant field acting on j due to the acceleration of i is in fact fully retarded. Moreover, the radiation damping force in i is full strength. Note that there is no question of retarded radiation flowing away into the empty spaces beyond j. Any radiation in the direction of j which is not absorbed by j is cancelled out, and the energy which would normally be transported beyond j appears instead in the *past*, in the far surface of the absorbing screen. This is an example then of the 'zag' diagram due to Gold (1967) (figure 6).

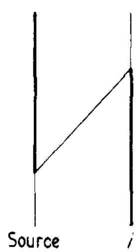

Figure 6.

The above two solutions of the incomplete absorber problem are each associated with the two different interpretations of the absorber theory already outlined. The first solution belongs to the Hogarth–Hoyle–Narlikar picture, because it requires the absorption of advanced radiation in the sense of figure 2(b), where the world lines there labelled by j refer now to the particles on the inside surface of the screen. Expressed in more usual 'forward time' language, this requires the cooperative spontaneous excitation of the screen particles at just the right moment to emit a coherent wave to converge on i, arriving near i at the moment of acceleration. According to the principles of statistical mechanics, this is extremely improbable, so that the first solution is rejected on the same grounds as the Hogarth–Hoyle–Narlikar interpretation.

The second solution envisaged by Wheeler and Feynman is, however, consistent with thermodynamics, because it requires absorption of the advanced radiation in the sense of figure 7, which should be carefully contrasted with figure 2(b).

The relevance of the model discussed above to the real universe will now be explained. In the conventional big bang theory, the cosmological material is highly compressed in the early stages, and opaque to electromagnetic radiation. After about 10^5 years of

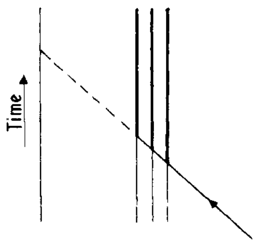

Figure 7.

expansion, the temperature falls below about 4000 K so that hydrogen recombines, and the cosmological material becomes transparent. Thus, for an observer at our own epoch in a universe described by an ever-expanding Friedmann model, a future null line extended in an arbitrary direction in space will almost certainly not intersect absorbing material, whereas the same null line extended backwards into the past, and hence in the opposite spatial direction, will intersect absorbing material in the big bang. The situation is thus analogous to figure 5.

There is one important difference, however, The cosmological frequency shift due to the expansion of the universe will raise the energy density of the 'incoming' advanced radiation in the primeval fireball to a degree far in excess of the energy density of the matter. So unlike the case of figure 5, where a small amount of radiation energy striking the left of the screen may easily be converted to heat, there is no way in which this enormous radiation energy density in the universe may be lost before decoupling of matter and radiation, unless it were to be absorbed in a previous contracting phase of the universe. Note that a temporary transfer of energy from radiation to matter is not sufficient, because the re-radiated energy cannot then in turn be absorbed in the future, so that it must appear again as more blue-shifted radiation in the past, in accordance with the remarks made above concerning figure 6. There is thus an inbuilt instability, which causes an escalation of electromagnetic energy density in the early expansion phase. Such an instability appears to be a general feature of systems which possess a conjunction of advanced radiation and entropy increasing processes (Davies 1974, p 130). Therefore, in the absence of a modification of the big bang model, the ever-expanding, and hence transparent Friedmann models are apparently inconsistent with the Wheeler–Feynman theory altogether, even when this theory is used in its widest sense to permit the explicit occurrence of advanced effects. These remarks do not apply to the re-contracting models; such models do not show advanced effects, though, in conventional statistical mechanical situations (advanced fields can be obtained in recontracting cosmologies by appropriately contrived boundary conditions which are inconsistent with the usual, but not sacred, statistical assumption of equal *a priori* probabilities (Gold 1962, Davies 1972b)).

In the experiment of Partridge, the power loss from an emitter radiating first into free space and secondly into a laboratory absorber is compared. If the universe had both past and future null cones partially transparent then a suitable experimental arrangement of this type would detect the presence of advanced radiation. However, even if our universe were of this structure, the advanced radiation would still be absorbed by the Earth or the rear of the emitter in Partridge's experiment (see figure 8). No advanced radiation would approach from the right towards the emitter, as the absorption on the left of retarded radiation from the source by the near side surface of the Earth is complete.

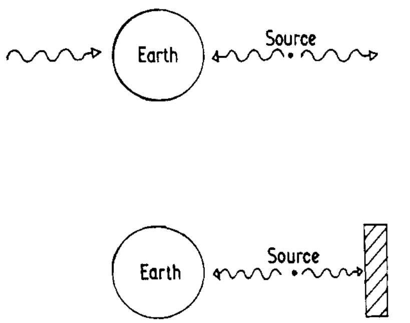

Figure 8.

Conversely, no advanced radiation from the left would be detected, as it would be absorbed on the far side surface of the Earth. A positive result would only be obtained if the experiment were performed away from the Earth with a very small source (no internal absorption) radiating in opposite directions at once.

In the experiment of Heron and Pegg it is proposed to arrange for periodic absorption of the advanced component of radiation from a source, leaving the retarded component unabsorbed (this can be done with a series of changing choppers). The principle of the experiment is based on the Hogarth–Hoyle–Narlikar interpretation. That is, the phrase 'absorption of advanced radiation' is used in the sense of figure 2(*b*), so that these authors aim to achieve the situation depicted in figure 9. If this situation could be achieved, then the power output from the source would fall drastically, essentially because the energy flow out of the source in the form of retarded radiation would be more or less compensated by the flow into the source from the advanced radiation.

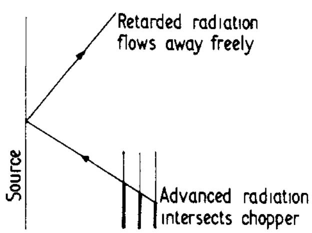

Figure 9.

Unfortunately, it cannot be accepted that the laws of thermodynamics would obligingly invert in the chopper at just the right moment merely for the convenience of the experiment. In fact, with normal thermodynamic behaviour, the situation is as shown in figure 10, where any advanced radiation from the source would be absorbed in the side of the chopper remote from the source. Therefore a null result must occur. This is even more so on account of the fact that the advanced radiation approaching the chopper from the direction indicated in figure 10 would be absent anyway, due to complete absorption by the Earth of the corresponding retarded radiation from the source, emitted to the left in the figure.

That the Hogarth–Hoyle–Narlikar interpretation leads to a nonsensical result in this case is apparent if it is contrived that the same chopper absorbs both the retarded radiation from one experimental source at the same time as it 'absorbs' advanced

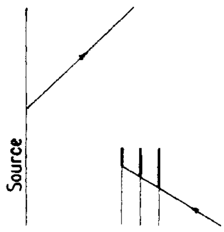

Figure 10.

radiation from another. One then obtains the totally ambiguous situation depicted in figure 3.

It is concluded that no terrestrial experiment can detect advanced radiation.

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