In Fig. 5 and Fig. 6 we show the development of distributions belonging to the parameters $N = 25$; $\kappa = 1.5$, $\delta = 0$ (hence belonging to a symmetric stationary solution) starting from a symmetric and asymmetric initial condition (see Fig. 5 and Fig. 6, respectively). The remarkable fact is, that - because of the high adaptation trend - the asymmetrical distribution first developes into a strongly biased distribution, before it relaxes into the symmetrical stationary distribution with an extremely long transition time.

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The Relation of Local Time Asymmetry to Cosmology

Jayant V Narlikar
Tata Institute of Fundamental Research, Bombay, India

Abstract

Biological evolution implies time-asymmetry. Thermodynamics also exhibits time asymmetry through its second law. Electromagnetic radiation is a time asymmetrical phenomenon. It is suggested that the various time asymmetrical phenomena in nature are related and their understanding may require us to consider the large scale structure of the universe. Some ideas which relate cosmological time asymmetry to the one-sidedness of radiation are described. It is also suggested that issues relating to the foundations of quantum theory such as the collapse of the wavefunction, on interaction with the observer might be related to the large scale structure of the universe.

1. Introduction

One of the basic mysteries of nature is the existence of phenomena exhibiting one-sidedness of time. All living systems age with time, showing that biology has 'something' in it that causes this time asymmetry. The second law of thermodynamics shows that for isolated systems evolution occurs in such a way that the total entropy cannot decrease. In a different context, the phenomenon of electromagnetic radiation shows unidirectionality of time : the radiation is always seen to move outwards leading to a loss of energy from a bounded system.

The mystery is not why such time-asymmetric phenomena exist, rather it is that these phenomena arise in spite of the fact that all known basic laws of physics are time-symmetric. Why should nature choose to have a time arrow when, by all indications so far, its basic machinery is guided by time-symmetric laws?

In a seminar devoted to the discussion of 'living state' it is a very pertinent question to ask : "What is the cause of time-asymmetry in a living system?" Biologists tend to answer this question (or to look for an answer to this question) within the framework of thermodynamics. Indeed, valuable inputs into this question have come from non-equilibrium thermodynamics. I do not question this point. I would like to point out, however, that thermodynamics may not have the complete answer. In this work I want to highlight certain nonlocal theories of basic physics which widen the scope of our enquiry from the 'local' to the 'cosmological' domain. The result of such an input is to relate the local time-asymmetry to the time-asymmetry manifested through the expansion of the universe.

2. The Wheeler-Feynman Theory

In 1945, J. A. Wheeler and R. P. Feynman [*1*] took the first step towards the above demonstration when they gave a formulation of classical electrodynamics in terms of action at a distance. I will avoid complicated mathematics here and will try to capture the essence of the Wheeler-Feynman theory in as nontechnical terms as possible. Let me begin on a historical note.

The notion of action at a distance was first used in a physical law by Isaac Newton when he stated the law of gravitation. The success of this law must have inspired Coulomb to formulate his law of electrostatic attraction/repulsion as an action at a distance law. Both the Newtonian and Coulombian laws were empirical in character and they were to be judged by their performance in the observational and experimental arena. Because electricity is a much stronger force than gravity at the laboratory level, Coulomb's law could be tested more thoroughly than Newton's; and it was found wanting. The discrepancies between the predictions of Coulomb's law and the behaviour of rapidly moving electric charges were indeed considered serious enough to warrant modification of the law.

In this context it is worth mentioning that Gauss had appreciated the likely avenue of resolution of the discrepancies. In 1845, in a letter to Weber, Gauss mentions that the notion of instantaneous action at a distance (a legacy of Newton's law of gravitation) may have to be modified to the notion of action travelling at a finite speed. In hazarding the guess that the action propagates with the speed of light, Gauss anticipated the developments of two decade later when in 1864 Maxwell resolved the problem in an altogether different way.

Maxwell utilized Faraday's notion of the 'field' as an intermediary between electric charges. Maxwell's equations describe how the movement of charges generate ripples in the electromagnetic field that pervades the space. These ripples travel in vacuum with the speed of light and communicate electromagnetic effects from one charge to another. Maxwell's theory was the first field theory and its successes in the laboratory went a long way to establish field theory as the mode of describing interactions in physics.

However, the action at a distance concept was revived again by Schwarzschild, Tetrode and Fokker using the notion of *delayed* action as conceived by Gauss. In this revised version of the law if we have two typical world points A and B on the world lines of two electric charges a and b, then A affects B and vice versa if and only if A and B can be connected by a light ray.

The revised version preserved the symmetry between interacting particles as required by Newton's third law of motion; it conformed to the Lorentz invariance of special relativity and led to a new quantum electrodynamics which, in many formal ways resembled Maxwell's field theoretic electrodynamics. Yet, this law had one difficulty which made its application to real life almost impossible. As can be seen from the two-particle example cited above, if B is to the future of A, the effect of B on A is *backwards* in time. In other words, the principle of causality (stating that causes precede their effects) was violated.

It was this difficulty that Wheeler and Feynman sought to resolve exactly a century later than Gauss's original suggestion to Weber. To understand the essence of the Wheeler-Feynman theory let me introduce the notion of *advanced* and *retarded* effects. I do this with the example of an accelerated electric charge a.

Maxwell's equations tell us that when an electric charge accelerates, it generates wavetype disturbances in the ambient electromagnetic field. In a typical *retarded* wave, the disturbance emanates from the immediate neighbourhood of the charge and propagates outwards with the speed of light c. Thus a disturbance starting out at time $t = 0$ at a will reach a point P at distance r at the time $t = r/c$. Such a retarded wave is consistent with causality and is found in nature.

What is *not* consistent with causality and *not* found in nature is the *advanced* wave. This wave travels backwards in time and, in the above example it was at P at the time $t = -r/c$. Thus the observer at P knew r/c time *before* the source acceleration that such a disturbance would be generated by a at $t=0$.

In practice, the theoretician throws away such peculiar solutions when discussing actual experiments. In other words, he rejects one-half of all the solutions theoretically available because they do not conform to the causality principle. He selects retarded solutions and discards the advanced ones to be consistent with causality. Such a procedure leaves open the more fundamental question : "Why does the causality principle operate in nature?" To answer it by stating that this is so because the retarded solutions only operate in practice is to argue in a circle! We need some deeper consideration than so far given to justify our rejection of the retarded solutions. Wheeler and Feynman give such a justification.

Taking the Schwarzschild-Tetrode-Fokker theory into consideration Wheeler and Feynman argued that each electric charge a produces a time symmetric disturbance written symbolically as

$$A^{(a)} = \frac{1}{2} A^{(a)}_{ret} + \frac{1}{2} A^{(a)}_{adv} . \qquad (1)$$

Thus there is no preference for retarded solution in the case of a single charge.

However, the real world is not made of a single charge. There are many electric charges distributed all over the universe. [It is estimated that there may be $\sim 10^{80}$ elementary charges in the observable universe.] Wheeler and Feynman argued that when a typical charge a is moved, all the rest of the charges in the universe instantly respond to produce an overall reaction $R^{(a)}$ to its motion. The net effect of a's motion is therefore not just $A^{(a)}$ but

$$F^{(a)} = A^{(a)} + R^{(a)}. \tag{2}$$

How can all other charges respond instantaneously, when we have just seen that all interactions travel with a finite speed c ? The answer to this question is simple. If charge a moves at $t = 0$, a typical charge b at a distance r will experience the retarded effect of a at time $t = r/c$. It will then respond via the advanced mode so that its response will arrive back at a at the time

$$t = \frac{r}{c} - \frac{r}{c} = 0 , \tag{3}$$

i.e., instantaneously! Notice that the actual distance r of the charge b from a does not enter this argument. Thus distant charges respond as fast as the nearby ones.

The magnitude of response, however, decreases with distance. The reaction from a charge at a distance r drops faster than $1/r^2$ and so the net effect of all charges in the universe is *finite*. Wheeler and Feynman found that in a static uniformly dense universe

$$R^{(a)} = \frac{1}{2}\left\{A^{(a)}_{ret} - A^{(a)}_{adv}\right\}. \tag{4}$$

Putting (1), (2) and (4) together we see that the net effect is

$$F^{(a)} = A^{(a)}_{ret} . \tag{5}$$

In other words, the response from the universe breaks the symmetry between advanced and retarded disturbances and leads to the observed retarded disturbance. Notice that the response $R^{(a)}$ in (4) has a minus sign in the right hand side, thus exhibiting an asymmetry. It is the first hint that we have that the universe may play a role in generating time asymmetry.

The Wheeler-Feynman theory is known as the absorber theory of radiation since it can be shown that in order to generate the appropriate response (2) the universe must totally absorb all radiation from the charge a. In the retarded case the absorption must occur along the future light cone of a while in the advanced case it occurs along the past light cone.

3. The Expanding Universe

The above argument is, however, incomplete. It does not elucidate why a time-asymmetric response like (4) emerged from the calculations of Wheeler and Feynman. These authors, as mentioned earlier, assumed the universe to be *static*, and a static universe is time-symmetric. How can a time-symmetric universe generate a time-asymmetric response?

A closer analysis of the Wheeler-Feynman calculation shows that it goes through even if we change t to $-t$. All advanced disturbances become retarded and vice versa under such transformations. Thus while (1) is unchanged (4) changes sign and (5) changes to

$$F^{(a)} = A^{(a)}_{adv} . \tag{6}$$

Thus, just as retarded solutions were possible, so are the advanced solutions. Apparently we are no better off in this theory than in the field theory of Maxwell.

Wheeler and Feynman appreciated this conundrum and they resolved it by an appeal to thermodynamics. To them the second solutions (6) appeared unphysical since it involved initial conditions that were highly unlikely. [For example, the second solution requires a typical electric charge b to move in such a way that *after* receiving a's signal it comes to rest!] So they ruled out such a solution on thermodynamic grounds. And by so doing they established a connection between the time-asymmetries of electromagnetic radiation and thermodynamics.

However, in reaching this conclusion the two authors missed an important point, namely that the universe is *not* static. It is expanding and hence it is *not* time symmetric. We cannot therefore argue that (6) would necessarily follow from (5) by changing t to $-t$. For, under such a transformation the expanding universe changes to a contracting one.

Hogarth [2] was the first to point this out. He and later, Hoyle and I [3] investigated the Wheeler-Feynman theory in expanding world models. As suspected, we did find a difference in the values of the response function $R^{(a)}$ in the advanced and retarded cases. The absorbers in the past and the future were found to behave differently. However, something more interesting emerged, that was not expected. Not all expanding models behave in the same way.

The difference in behaviour may be illustrated with two types of models. In cosmologies where the universe originated a finite time ago in a gigantic explosion the consistent solutions is of the advanced type. Thus the result (6) holds, not (5).

In the steady state model which had no beginning and in which matter creation is taking place in a continuous manner the consistent solution is of retarded type given by (5) and not of the type given by (6). Thus in the big bang cosmology the past light cone absorbs perfectly while in the steady state theory the future absorber is perfect.

4. Quantum Electrodynamics

In the early 1960s when the balance of evidence between the two types of cosmologies was fairly even, the above analysis seemed to provide a strong support to the steady state model. For, this model alone seems to generate the correct time asymmetry for cosmology and electrodynamics together. Nevertheless, all discussion so far has been at the classical level and one may well ask : what about quantum electrodynamics?

At first examination, such phenomena as the spontaneous transition of electron in an atom, the phenomenon of black body radiation, the effects of pair creation and annihilation, Lamb shift and the anomalous magnetic moment of the electron all seem to imply that electrodynamics cannot be described except through a quantum field theory.

This myth has been exploded! The work by Hoyle and myself [4 , 5] has shown how to quantize the Wheeler-Feynman theory and how to describe all the above phenomena without requiring the independent existence of the electromagnetic field. Moreover, the somewhat arbitrary cut off procedures employed in the renormalization of divergent integrals in the perturbation expansion receive a clear physical interpretation in this work.

I would like to highlight another non-local aspect of this work which has a bearing on the foundations of quantum mechanics. So far, the notion of the 'collapse of the wavefunction' has been somewhat difficult to accept and has received considerable attention from various physicists. Basically, the problem is as follows.

Imagine a quantum mechanical system which has been left isolated and which would be observed at some stage by an observer. Prior to the observation the system is described by a wavefunction which is a superposition of the many stationary states of the system $\{\psi_n\}$:

$$\psi = \sum_n C_n \psi_n . \qquad (7)$$

Here ψ_n is the n^{th} stationary state and C_n the probability amplitude of the system being found in this state by the observer. It is assumed that in the process of observation the wavefunction collapses from (7) to one of the ψ_n's. Attempts are made to relate all this to the consciousness of the observer.

At this stage it is worth pointing out one fact. Recall that the C_n's being complex numbers are not really measurable. Probabilities $|C_n|^2$ are the measurable quantities. The connection of this fact with what I have been describing earlier is established from the result that the quantum mechanical response of the universe (the analogue of $R^{(a)}$) appears in our work not as an amplitude but as a probability.

It is therefore possible that the collapse of the wavefunction occurs not only through an interaction between the system and the observer but it also brings in the response of the universe. Because this component is missed out from the usual discussions of this problem the outcome appears somewhat mysterious. A detailed discussion of this problem which includes the response of the universe has been given by Hoyle [6] recently.

5. Conclusions

I have given a schematic account of how the time asymmetries in cosmology, electrodynamics and thermodynamics could be related. If one follows the action at a distance approach the moral one arrives at is that even in the apparently purely local phenomena the large-scale behaviour of the universe may be playing a subtle role. I believe that with further advances in our knowledge of what living matter is, we can link the biological time asymmetry also with the structure of the universe.

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