

The Universe and the Arrow of Time

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The events which we see in everyday life can be classified into two categories: the reversible events and the irreversible ones. A simple way of understanding the difference between the two types is as follows. Suppose we take a film of the event in question and run the film backwards. Do we observe in real life the event shown on the film run in this way? If we do, then the event is reversible, otherwise it is irreversible.* For example, a ball bouncing on a floor in a perfectly elastic manner is a reversible event. So is a pendulum swinging in a frictionless medium. On the other hand, a cup falling on the floor and breaking up is an irreversible event.

The notion of an 'arrow of time' arises from the irreversible events. Consider first what happens in space as against in time. In space there are three dimensions, and free movement is possible in each dimension in either direction. In time, which has one dimension, this does not seem to be true. We are conscious of a 'present' instant which separates the past from the future. Movement seems to be possible only from the former to the latter. Since an irreversible event proceeds only in one way we can make an absolute distinction between the past and the future in respect of that event. That is, if we are shown two snapshots of the event, we can say which was taken earlier and which was taken later. There is no such absolute distinction in space, say between left and right or top and bottom. The arrow of time may be described as arising from our ability to place the events in real life in a chronological sequence.

Why should there be such an arrow? A physicist would like to think that the arrow of time may arise from the fundamental laws of physics which are supposed to regulate the phenomena observed in real life. Yet, a glance at the fundamental laws does not provide any clue: the laws are time-symmetric. This means, any event taking place according to these laws is reversible. If we make a film of such

* The Discourse began with a film describing the two types of events. The author is grateful to Mr Coates and the staff of the Royal Institution for making the film.

an event and run it backward, the new event seen should also be possible according to these laws. Clearly, the existence of irreversible events indicates that this rule does not always operate. Something more is needed to understand the arrow of time. There have been various attempts to introduce this extra something into physics. I want to describe a somewhat unorthodox point of view, and for this I begin with the discussion of a well known irreversible event—the electromagnetic radiation.

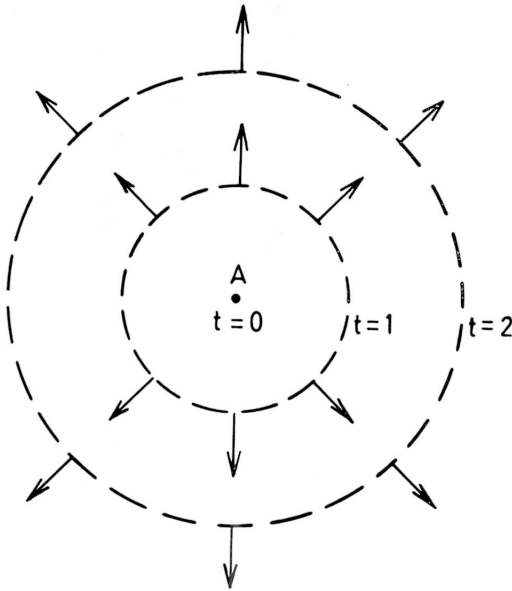


Fig. 1. *Retarded Waves*: When the electric charge A oscillates, it emits retarded waves which travel outwards. The wave at A at time $t = 0$, reaches a distance of 1 light hour at $t = 1$ hour, a distance of 2 light hours at $t = 2$ hours and so on.

We know that when a wireless transmitter is set going it gives out electromagnetic waves. These waves arise because of to and fro movement of electrical charges. The situation is described mathematically by the fundamental laws of electricity and magnetism, as given by Maxwell about a hundred years ago. Maxwell's equations describe how electromagnetic waves emanate from an oscillating electrical charge and propagate outward. A simplified situation is described in Fig. 1. The waves originating from the charge reach a

distant point at a *later* instant and hence are called 'retarded' waves. Such waves carry energy with them and, as a consequence, the charge loses energy. This event is irreversible and enables us to determine an arrow of time. The loss of energy by the electrical charge determines a chronological sequence.

However, Maxwell's equations are time-symmetric and therefore should permit the reverse of the situation just described. Corresponding to the situation described in Fig. 1 we should also see the situation described in Fig. 2. This has electromagnetic waves coming towards

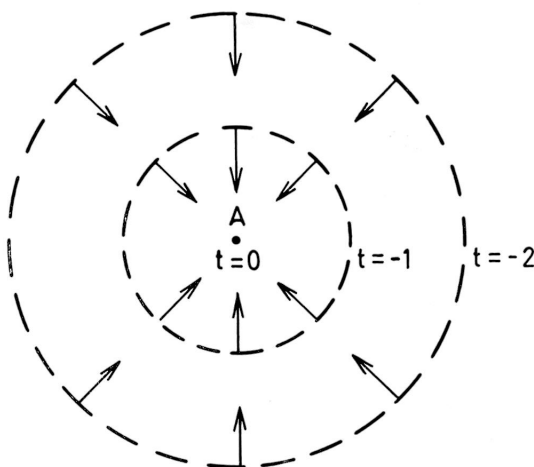


Fig. 2. *Advanced Waves*: These are obtained from the retarded waves by letting time run backward. So the wave at A at time $t = 0$, is one light hour away from A at time $t = -1$, and so on. The advanced wave appears to converge on A.

the electric charge, rather than leaving it. Or we may say these waves are leaving the charge and travelling *backward* in time. Such waves are called 'advanced' waves. If advanced waves also existed in nature, we would have seen the phenomenon of radiation in the reverse. This would have meant that an oscillating electric charge did not always lose energy, but also gained it. Clearly the existence of the electromagnetic arrow of time already described is connected with the rejection of advanced waves by nature.

Before I go further into this question I want to mention another

arrow of time. This is provided by the behaviour of the universe as a whole. The present astronomical observations suggest that the universe is made up of a large number of galaxies. A typical galaxy, like our own, has ten to one hundred thousand million stars like the Sun. The galaxies are separated from one another by distances of the order of millions of light years. Observations of these galaxies, initiated by Hubble and extended by subsequent astronomers, have revealed a remarkable property. The galaxies appear to be receding from one another in a systematic way. The relative velocity of recession of two galaxies is proportional to their distance.* This is known as Hubble's law. This systematic motion of the galaxies is often described by the statement that the universe is expanding.

The expansion of the universe is explained by the theoreticians¹ in terms of the fundamental physical laws. Various models have been constructed which simulate the behaviour of the observed universe. I shall be concerned here with two types of models. In the so called 'big-bang' models, all the matter in the universe was created a finite time ago, with a big explosion. The receding galaxies are the debris of this explosion. Against this type of model, we have others where the matter was not created in a once-for-all explosion. Rather it is being created in small doses, continually. The appearance of new matter pushes the existing matter away, and hence the recession. The best known model of this class is the steady-state model, which says that the universe is unchanging when observed over long intervals of time. In this model the new matter appears at a steady rate to take the place of the old matter which has thinned away by expansion.

In either type of model the expansion of the universe gives rise to a cosmological arrow of time. In Fig. 3, we have two galaxies, *A* and *B*, at three different instants of time. We can say that the instant 3 occurs later than 2 and 2 occurs later than 1 because the distance between *A* and *B* has increased from 1 to 2 and from 2 to 3. No such time ordering would have been possible if the galaxies were moving at random.

The interesting question now arises: Is there any connection between the cosmological arrow of time and the electromagnetic arrow of time previously described? In other words, can we say that advanced waves are not possible because the universe is expanding?

* The actual observations measure red shift and apparent brightness of the galaxies. These are then related to velocity and distance.

The reasoning I will describe now answers this question in the affirmative, provided we have a suitable model of the universe.

There are two ways of describing the phenomenon of electromagnetism. One of these—Maxwell's theory—makes use of two interdependent entities: the electric charge and the electromagnetic field. Two electrical charges, A and B , interact in the following way. When charge A moves, it disturbs the field. The disturbance so created travels outwards, much in the same way as waves move outwards in water when a pebble is dropped into it. The disturbance eventually arrives at B and disturbs it. In this way the influence is propagated from A to B , via the retarded waves in the ambient field.

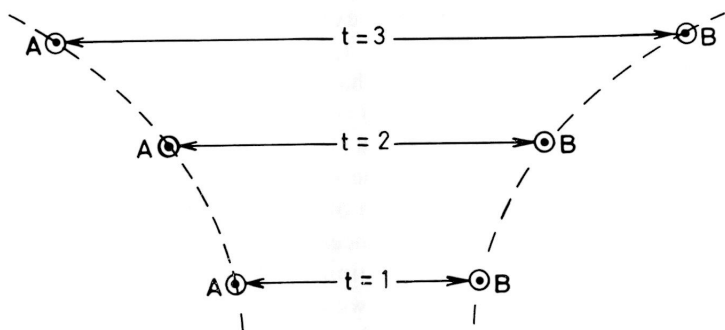


Fig. 3. *Cosmological Arrow of Time*: The expansion of the universe determines an arrow of time. The galaxies A and B are receding from each other. So they were nearer each other in the past and will be further apart in the future.

B influences A in the same way. In the other picture, with which I will presently be concerned, the charges A and B interact directly, without the medium of a field. This picture, known as action at a distance, is older than the field picture, and was first inspired by Newton's law of gravitation. The concept of action at a distance did not work successfully, however. The fault lay not with the basic concept, but the way in which it was originally stated. It was then assumed that the charges interact instantaneously, *i.e.*, the influence from A to B (and vice versa) propagates with infinite speed. When Einstein's special theory of relativity became well established at the beginning of the present century, it laid down the rule that no physical influence should propagate faster than light. The concept of action

at a distance had therefore to be redefined to take this into account.

However, this led to fresh troubles. Imagine two charges, *A* and *B*, situated one light hour apart. Suppose influence from *A* to *B* propagates with the speed of light. If *A* is disturbed, say at 4 pm, *B* will feel the effect at 5 pm. So far, so good. But now another law

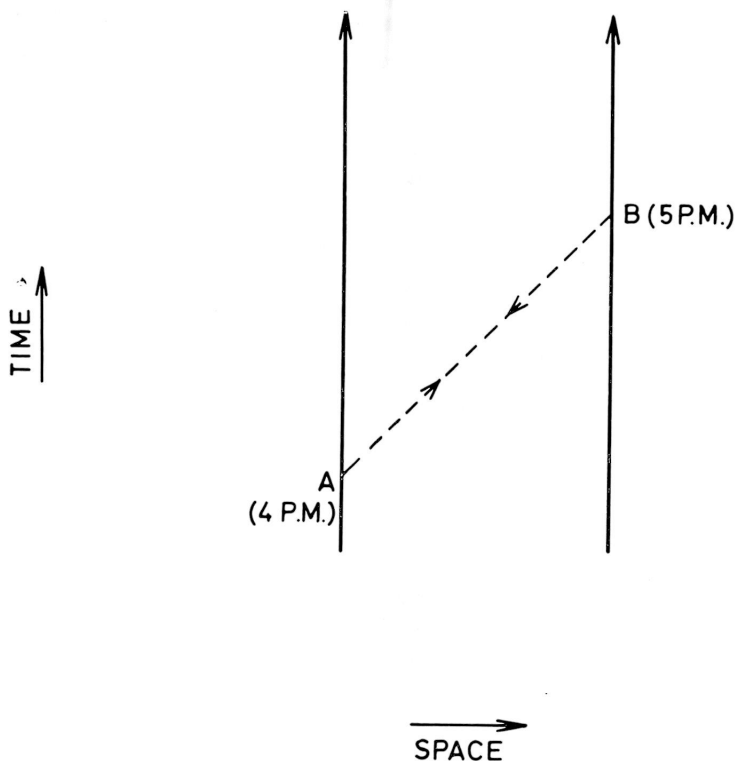


Fig. 4. *Action at a distance*: The influence from *A* to *B* takes one hour to travel, if *A* and *B* are one light hour apart. The original disturbance from *A* leaves at 4 pm and hits *B* at 5 pm. The immediate reaction from *B* reaches *A* at 4 pm.

comes into effect: Newton's third law of motion which states that action and reaction are equal and opposite. So *B* must react back on *A*, and the reaction must propagate backwards along the same track as *A*'s original action. The word 'backwards' refers not only to space but also to time. The situation is illustrated in Fig. 4. The

influence of B on A leaves B at 5 pm and arrives at A at 4 pm! A retarded influence from A to B provokes an advanced reaction from B to A , and vice versa. Thus the action at a distance theory deals not only in retarded influences but also advanced ones, and apparently both have an equal status.

At this stage we might pause and consider the consequences of having advanced as well as retarded signals in the universe. If we were able to communicate with and influence our past, we would encounter paradoxical situations. One such situation is described below.

Imagine two observers, A and B , one light-hour apart. They decide to communicate with each other according to the following rules. A sends a signal to B at 4 pm if and only if he does not hear from B at 4 pm. B sends a signal to A at 5 pm if and only if he hears from A at 5 pm. Does A send a signal or not? A little consideration would convince you that either of the two logical possibilities is untenable.

The appearance of such paradoxes led physicists to abandon the concept of action at a distance, until about twenty-five years ago. Two physicists, J. A. Wheeler and R. P. Feynman,² pointed out that such paradoxes arose, not because the concept of action at a distance was wrong, but because proper account was not taken of the reaction from the universe. In the above paradox, for example, we have not taken account of the other charges $C, D \dots$ in the universe. Can they make a difference?

Let us take charge A as our origin of coordinates. Suppose a charge, C , is located at a distance of n light years from A . We set the charge A in motion at time zero, say. The retarded influence from A will reach C n years later. Then C will move and send back advanced and retarded influences to A . The latter will arrive at A , $n + n = 2n$ years after the original influence left A . The former, on the other hand, arrives back at A , $n - n = 0$ years later, *i.e.*, as soon as the original influence left A ! Thus the charge C will send its advanced reaction to A instantaneously, no matter how large n is. In other words, there exists a possibility that the distant parts of the universe will react back on charge A in a significant way. So, in formulating paradoxes of the aforementioned type it is wrong to ignore the rest of the universe.

What is the reaction of the universe as a whole? We cannot answer the question until we say what type of universe we live in. This is

where the different models of the universe, mentioned before, come in. In their original calculation Wheeler and Feynman assumed the universe to be static, *i.e.*, non-expanding. They found that such a universe sends back a reaction which damps out the advanced signals.

We can express this fact by a few simple symbols. If we take charge A alone, we know it radiates equally via advanced and retarded waves. So we write the disturbance leaving A as:

$$F = \frac{1}{2} (\text{Retarded}) + \frac{1}{2}(\text{Advanced}).$$

To this must be added the reaction from the universe. The reaction calculated by Wheeler and Feynman turned out to be:

$$R = \frac{1}{2}(\text{Retarded}) - \frac{1}{2}(\text{Advanced}).$$

The total disturbance near A is therefore:

$$T = F + R = (\text{Retarded}).$$

Notice that the advanced, *i.e.* 'backward in time' disturbances are cancelled out altogether. So we do not have any paradoxes. Also, we see why a wireless circuit radiates retarded waves—because the universe requires it to.

The Wheeler-Feynman calculation had one shortcoming. It did not take account of the expansion of the universe. Subsequent investigations have remedied this.^{3,4} These lead to an interesting observational test of the various cosmological models. This is as follows. We take a particular model and work out the reaction, R , of the universe. If it turns out to be of the form obtained by Wheeler and Feynman, the model passes the test. If not, it fails—because in such a model advanced signals are not totally destroyed and paradoxes arise.

When we apply such a test to the ever-expanding big-bang models, we find that they fail the test. The models with continuous creation fare better. For example, the steady-state model passes the test.

The reason for this is not difficult to see. In an expanding big-bang model, the density of matter steadily diminishes. So a retarded signal from A , as it travels into the future, encounters fewer and fewer charges per unit volume. The combined reaction from these charges is not enough to give the required form. In models of continuous creation, new matter is always appearing. So, in spite of the expansion,

the density of matter need not diminish. Thus there are enough charges in the future to send back the required reaction. This test therefore is decisively in favour of models with continuous creation.

Notice that this test did not require a telescope of any kind. The observation of pure retarded signals emitted by a wireless transmitter in a terrestrial laboratory is enough to tell us a lot about the large scale structure of the universe. Some of the other cosmological tests do involve telescopes of various kinds, however. In looking through a telescope we examine the universe as it was in the past.* The test described here examines the future state of the universe and is, in a sense, complementary to the conventional telescope-tests. Clearly, a cosmological model must pass all the observational tests imposed on it.

To return to the action at a distance theory. We now see that it provides a link between the local behaviour of matter and the large structure of the universe. If we accept this theory, rather than Maxwell's, we are able to say that charges radiate retarded waves because the universe expands. The arrows of time in electromagnetism and cosmology are intimately connected.

I would now like to end with a few comments on recent developments.⁵ The electromagnetic effects I have been describing are classical, *i.e.*, before the discovery of quantum theory. Quantum theory has revealed a rich variety of effects, some quite unexpected from the pre-quantum days. The action-at-a distance theory has been shown to work well even in this case. Here again, it is essential that the response of the universe to a local experiment is properly taken into account. One example is as follows.

In atoms electrons go round the nucleus in various orbits. Unlike classical theory, the quantum theory permits a discrete set of orbits, each with a specified total energy. It is possible for an atomic electron to change orbits thereby gaining or losing energy. Such transitions can occur in two ways. They can either be induced by external radiation falling on the atom, or they can be spontaneous. In the former case the electron can either 'jump up' (*i.e.*, gain energy) or 'jump down' (lose energy). In the latter case it can only jump down. The energy lost by the electron is emitted as electromagnetic radiation. This is analogous

* The telescopes use electromagnetic waves which travel at the speed of light. Such waves from distant objects which are received by the telescopes now, must have left them long ago. So we see the objects as they were long ago.

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to the classical case of an oscillating charge radiating retarded waves. Why does an atomic electron not jump up spontaneously? The answer is similar to that of the question 'Why are there no advanced waves?' It is the expanding universe which causes the electron to jump down (and not up) when no other radiation is present.

To me this result is remarkable because it is the first step towards connecting the very large (the universe) with the very small (atomic physics). I hope further developments along these lines will form the subject of a discourse in the future.

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EXHIBITS IN THE LIBRARY

1. Series of displays illustrating scales of distance, density, time and interactions.
2. Papers by the lecturer.
3. Books and journals from the library of the Royal Institution.

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