

STEADY STATE DEFENDED

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The steady state theory still has a few adherents who rebel against the wholesale acceptance of the big bang which, by its very nature, assumes that there are aspects of the universe that can never be known. Little is understood about the big bang itself except that all information is destroyed as one approaches nearer and nearer to it, and that we can never know what preceded it or caused it—if, indeed, such phrases can have any meaning at all. By contrast the orderly progression of the steady state theory, in which the large-scale aspects of the universe have always been and always will be the same, still has a strong, aesthetic appeal.

One who has done much to shore up the structure of the steady state theory against the battering rams of awkward observations is Jayant V. Narlikar, formerly of the Institute of Theoretical Astronomy, Cambridge, and now Professor of Astrophysics at the Tata Institute of Fundamental Research, Bombay. L. H. J.

Right from its birth in 1948 the steady state theory has played an important part in the development of cosmology. Even its opponents, and there are many, will not deny this fact. On the theoretical front the radical ideas underlying the theory have provoked controversies. On the observational front the theory has been constantly under attack, but this is only to be expected. After all, unlike its rivals the big bang cosmologies, the steady state theory makes clearcut predictions which can be tested by observations. If, as Bondi suggests in the opening chapter of this volume, one criterion for a good scientific theory is that it should 'live dangerously', then this alone would give the steady state theory a flying start over its competitors!

However, for a scientific theory to live dangerously is one thing. But for the theory to die an untimely death in consequence is quite another. Have astronomical observations really killed the steady state theory? If this question were asked in an opinion poll of astronomers, a majority would probably answer it in the affirmative. Yet, history of science shows that theories are not discarded on a majority vote but only when the observations are unambiguously against them. Do the observational claims against the steady state stand up to an objective assessment of the data? I will examine this question in the central part of this chapter.

First, I would like to begin the discussion by describing what the theory is about, because considerable confusion results from time to time when the observers try to interpret what the steady state theory in fact has to say. Even its authors differ among themselves as to the proper approach to the theory. The approach of Bondi and Gold is a deductive one.

starting from one central principle. Hoyle's approach makes use of equations which are a modified form of those which describe Einstein's general theory of relativity.

Bondi and Gold argued as follows. In cosmology, we study the structure of the universe by looking at its distant parts and comparing them with our own neighbourhood. These observations are carried out by using electromagnetic waves, e.g. optical, radio, X-rays, etc., all of which travel with the speed of light. Therefore, when looking at the distant parts of the universe we see them as they were a long time ago. Any meaningful comparison of these distant parts with the ones nearby presupposes that the laws of physics are the same in the two cases. Since the universe, by definition, includes the study of *all* observable phenomena, we may expect the laws of physics also to be somehow determined by the universe as a whole. If the state of the universe was once very much different from what it is now, what guarantee do we have that the laws of physics were the same in the past as they are now? Indeed, the only way one can definitely guarantee that the laws have always been the same is by postulating that the universe has likewise always been the same. Bondi and Gold formulated this point of view in the form of the so called 'Perfect Cosmological Principle', which states that the universe, in the large, is unchanging in time as well as space.

A remark on the word 'perfect'. Even before Bondi and Gold, cosmologists did use a 'cosmological principle' in a restricted sense. This principle assumed large-scale homogeneity and isotropy of the universe at *any given epoch*. This meant that two observers at different locations in the universe but at the same epoch of time would see the same large-scale view of the universe in all directions. By adding the qualification 'perfect', Bondi and Gold wished to emphasise the large-scale regularity of the universe not only over space but also over time.

From the perfect cosmological principle Bondi and Gold deduced that the universe must always expand. The only other possibilities are that it is either static or always contracting. In either case, as Bondi himself shows in Chapter 1, we run into the Olbers paradox, with a very high or infinitely bright sky background. Only if the universe expands continually will the night sky remain dark. Incidentally, this is an example of the deductive power of the perfect cosmological principle, when taken together with the information available from our immediate neighbourhood.

One immediate deduction from this expansion of the universe is that new matter must be created continually.

The injection of new matter serves to keep the density of matter constant, as required by the 'steady state'. This is in contrast to the big bang models where matter is created once and for all in a single event. The steady state creation rate is extremely small, about one gramme of matter appearing in a volume of one litre in about a trillion trillion years. (Trillion = million million million.)

The reasoning leading to the perfect cosmological principle, and the deductive power of the principle are the attractive features of the Bondi-Gold approach. Nevertheless this approach has certain drawbacks. For example, it was never stated precisely over how large a scale of space and time the perfect cosmological principle applies. Clearly it must apply to some average condition of the universe, and a certain amount of fluctuation about this condition is to be expected. If an observer does not allow for this in the interpretation of his data, he is likely to conclude that he has found evidence against the theory when in fact he is merely observing a fluctuation from the average steady state. The lack of specification of the degree of departure from the steady state condition has thus led to confusion among those who want to interpret the predictions of the theory. Also, the theory lacks field equations which could tell us, as in the case of big bang models, how to relate quantitatively the various observable characteristics of the universe. There are no physical laws to tell where the new matter comes from. All we can say is that it is one of the consequences of the perfect cosmological principle.

Hoyle approached the steady state theory from another direction. He argued that a cosmological theory must answer the question: 'Where did the matter we now see around us come from?' This question is by-passed in big bang cosmologies, in which Einstein's equations describe the behaviour of matter only *after* it has been created. To study the actual creation process, Hoyle modified the Einstein equations by adding further terms to them. These terms provide an energy reservoir from which matter can be created. At first sight such an attempt might appear doomed from the outset. Any energy reservoir is expected to be depleted gradually for two reasons: firstly the fact that matter is being extracted from it means it loses an equivalent amount of energy according to the Einstein rule $E = mc^2$, secondly the expansion of the universe dilutes any reservoir of energy.

How can a steady state be maintained in spite of this? Hoyle got round this problem by an ingenious method. He made the cosmological reservoir of *negative* energy. The strength of such a reservoir *increases* by matter creation

because extraction of positive energy from a negative energy reservoir makes the original energy density even more negative. The two processes described above now work in the opposite sense and they are held in balance in the steady state universe. Departure from this balance can lead to fluctuations from the steady state picture, but now we have quantitative estimates about the extent of such fluctuations.

Of course, criticisms can be levelled against this approach. The concept of negative energy is unusual in physics, although it is worth pointing out that gravitation also has negative energy. On a local scale negative energy reservoirs present mathematical problems, especially in quantum physics. However, a preliminary investigation has shown that these difficulties are unlikely to be present when the reservoir is spread over the whole universe. A second, and more important criticism is that if we set out to modify Einstein's equations we can do so in a large number of ways—whereas a good physical theory should have as little arbitrariness as possible. To a great extent this criticism was met when Hoyle adopted the starting point suggested by Maurice Pryce in 1960. This introduces the simplest possible modification, where the energy source is a 'massless scalar field'. Even this field is not required in a more recent formulation given by Hoyle and Narlikar.

Having described the basic ideas underlying the steady state theory I can now examine how the theory has faced the many challenges placed in its way by observational astronomy. The first challenge came from the observed abundances of chemical elements. The work of Gamow and others had shown that heavy nuclei could possibly be synthesised from neutrons and protons in the early stages of a big bang universe. In the first few moments after the big bang the universe has a high temperature and density of radiation and matter, and these are indeed conditions suitable for nucleosynthesis. It was argued that such conditions are never present in a steady state universe which therefore fails to account for the presence of heavy elements. However, it was soon realised that the wide range of conditions operating inside the stars in their various evolutionary stages also permit the synthesis of all the observed elements. The pioneering work of Geoffrey and Margaret Burbidge, William Fowler and Fred Hoyle demonstrated in great detail how this is achieved. Indeed the tables were turned back on the big bang cosmologies when it became clear that the original expectation, that the nucleosynthesis could be done entirely in the big bang, is not correct. At best we can get hydrogen and helium from the hot big bang, but not the

heavier elements like carbon, oxygen, etc. For these we need the stars anyway! Recent calculations with high-speed computers have confirmed these conclusions.

The next challenge came from the Stebbins-Whitford effect. It is known that because of cosmological red-shift (the fractional increase in the wavelength of light from a distant source, when received by a terrestrial observer) the distant galaxies would appear redder than the nearby ones. Stebbins and Whitford found reddening in distant galaxies over and above that arising from the red-shift. This meant that galaxies at earlier epochs were systematically redder than they are now, thus implying a departure from the steady state situation. Subsequent work showed, however, that the effect was a spurious one, and there is no excess reddening.

I now come to two cosmological tests which have frequently claimed to have disproved the steady state theory. The first is the extension of Hubble's velocity distance relation and the second is the counting of radio sources.

Hubble's original observations, now nearly four decades old, showed a linear relation between the red-shift and the distance for nearby galaxies. These observations have since been extended to more and more distant galaxies, the most extensive work being due to Sandage and his collaborators with the 200-inch telescope at Mount Palomar. The main purpose of these observations is to measure accurately the rate of expansion of the universe and to try to distinguish between the different cosmological models. John Peach has given details of this work in Chapter 2.

The observations are plotted on the so-called Hubble diagram. On the x-axis we have the apparent magnitude and on the y-axis the red-shift of the galaxy. Apparent magnitude measures the faintness of the galaxy as seen from the terrestrial observatory. If all galaxies were equally bright intrinsically, the more distant they are the fainter will they appear. Thus we have a crude measure of distance along the x-axis. In Fig. 7 we have some theoretical curves predicted by a range of big bang models and the steady state model.

If we have a large number of galaxies with red-shifts, say in excess of 0.2, we may be able to tell which curve best represents the data. For red-shift values under 0.2, there is no substantial difference between the predictions of different cosmological models. And here we encounter a frustrating situation. Our measures of distance get less and less reliable for more and more distant galaxies. For red-shift values under 0.2, a fairly reliable measure can be obtained, as Peach described, by looking at only the brightest members of clusters of galaxies. From a study of nearby clusters it can

be ascertained that the variation of intrinsic brightness among this class of galaxies is not too great. However, if we now look for similar galaxies with red-shift values over 0.2, we find only three so far, with red-shift values 0.29, 0.36 and 0.46! The last of these was discovered with the help of radioastronomy in 1960. This red-shift belongs to a cluster of galaxies associated with the radio source 3C-295. It was hoped that more high red-shift galaxies might be discovered in this way by identification with radio sources. Although a number of identifications have been obtained, none have the high red-shifts we are looking for. So the conclusions depend essentially on three points!

A few years ago it used to be stated that the model best favoured by the data is one where the expansion of the universe is slowing down so that it will eventually contract. However, recent examination of the data indicates various ifs and buts associated with distance measurements, and the range of uncertainty is such as to permit a wide range of curves of Fig. 7, including the steady state curve.

At this stage we may ask 'What about the quasi stellar objects with their large red-shifts?' Red-shifts of the order of 2 are very common among the quasars. The discovery of early quasars raised the hope that they would settle this question one way or the other, and indeed the first few quasars did seem to lie on a well-defined line. This state of affairs was not to last for long however. In 1966, Hoyle and Burbidge pointed out that the quasars whose red-shifts were known then did not lie on any well-defined line but had a huge scatter. This conclusion has not been changed since the discovery of more quasars. A typical Hubble diagram for quasars (Fig. 8) looks a scatter diagram and only an eye of faith might spot a smooth curve running through the points. Indeed, one is led to suspect that because the quasars do not seem to follow the Hubble law, their red-shifts may not be due entirely to the expansion of the universe. In spite of such evidence, this conclusion has been resisted by many astronomers.

Perhaps the most controversial attack on the steady state theory comes from radioastronomy. This involves the counting of radio sources down to specified flux density. (Flux density is a measure of the amount of radiation received over unit area in unit time in a given frequency range.) The basic idea of this test is quite simple. Suppose we live in a simple universe in which Euclid's geometry holds, there is a uniform distribution of sources emitting radio waves, and all sources have equal strength. If we draw a sphere around us, the faintest looking sources in it will be

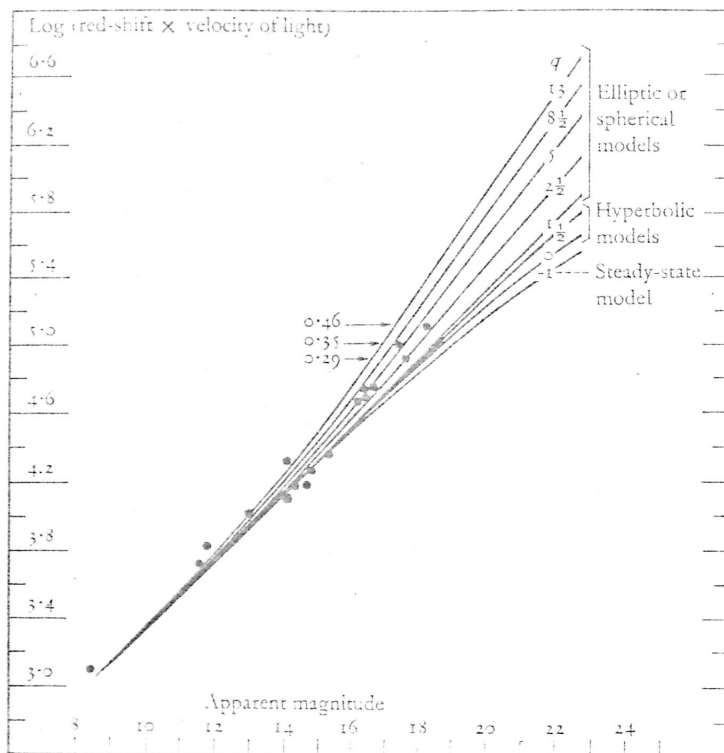


Fig. 7: Data by Sandage and Baum plotted as logarithm of red-shift against apparent magnitude.

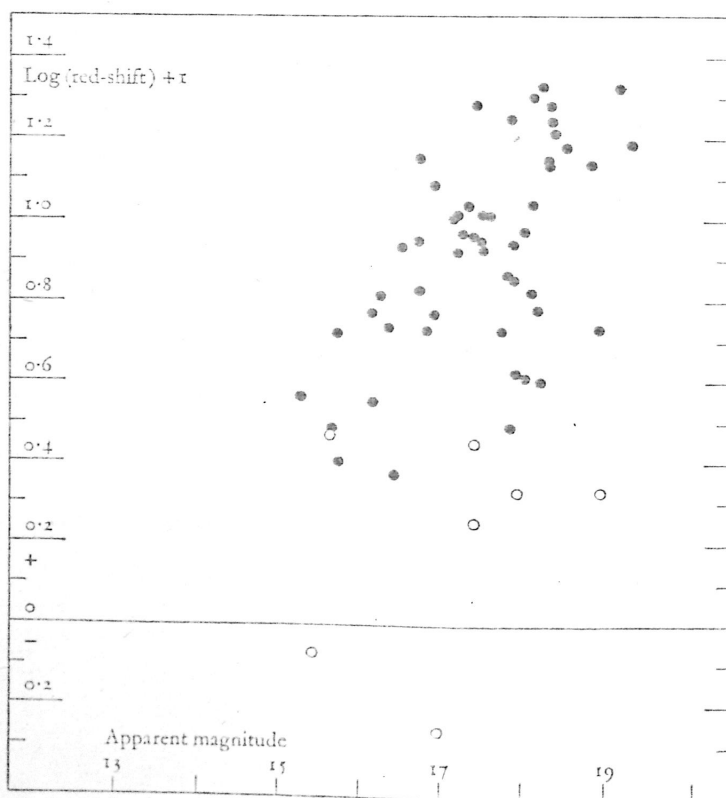
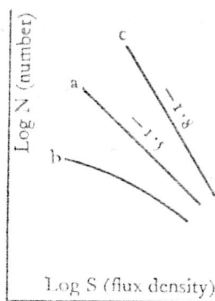


Fig. 8: Hubble diagram for quasars



- a: Euclidean universe
- b: Steady-state universe
- c: Observed curve
(3C-survey)

Fig. 9: Graphs of radio source flux levels against number observed N.

those on the boundary. The flux level of such sources will be inversely proportional to the square of their distance from us. On the other hand, if we count all the sources brighter than these on the boundary, they will be inside the sphere. Their number will be proportional to the cube of the radius.

In an expanding universe the above assumptions may have to be changed. If we keep the distribution of sources emitting radio waves and their strength unchanged but give up Euclid's geometry, we can easily work out the $\log N$ (number) $\log S$ (flux density) curve for any given cosmological model. Fig. 9 shows three curves. Curve a is the straight line with slope -1.5 . Curve b is that calculated for the steady state universe. Curve c, which is the observed curve, has slope -1.8 . The relative spacing of the curves above or below one another is not important; only their slopes are.

The observations have had a somewhat checkered history. Early Cambridge surveys by Ryle and his collaborators indicated a slope of -3 for the $\log N$ — $\log S$ curve, in violent disagreement with the curves a and b. Similar surveys of the southern hemisphere by Mills and his colleagues indicated a less steep slope, around -1.8 . Later Cambridge surveys also settled down to this value. The curve c shown is the 3C-curve (the third Cambridge survey). Further Cambridge surveys, the 4C and 5C, continue this curve to lower flux values. These surveys indicate that the curve begins to flatten at lower flux values, much as one would expect from a continuation of the steady state curve b. So the real controversy lies about source counts at high flux levels.

In the last few years more detailed work has been done at this end of the $\log N$ — $\log S$ curve. We have already seen that on the Hubble diagram the quasars behave in a peculiar fashion. They differ from galaxies in many ways and it seems somewhat artificial to count them together with galaxies. The revised 3C-catalogue can therefore be analysed in the following way. First we single out those sources which can be identified with objects seen through an optical telescope. Of these, those which are identified with galaxies are placed in one category. Those identified with quasars are placed in another. The unidentified sources form the third category.

The slope of $\log N$ — $\log S$ curve for the sources in the first category is not significantly different from -1.5 . However, a plot of red-shift against radio brightness for these radiogalaxies reveals no correlation at all. This means, the radiogalaxies differ widely in their intrinsic brightness and the assumption that all sources have equal strength made earlier is not valid. Thus we cannot use this $\log N$ — $\log S$ curve to prove or disprove cosmological models.

A similar situation prevails for the quasar radio sources. But, in this case the red-shifts are large. If the red-shifts are of cosmological origin, we could ascribe their $\log N$ — $\log S$ curve to a powerful evolutionary effect that contradicts the steady state theory. However, considerable doubt exists about the nature of quasars' red-shifts, as we shall see later.

The unidentified sources appear to hold the key to the whole question. Ryle and his group have argued that these sources are not nearby and their $\log N$ — $\log S$ curve which has a steep slope of -2.5 or so, indicates an evolutionary universe. Hoyle argues that they are comparatively nearby and the steep slope is not cosmologically significant. Hoyle's argument is illustrated briefly in Fig. 10. The line AB has slope -2.5 between flux levels .5 and 12.5, the 3C values at the frequency 408 MHz. At the high flux end B we have ten sources, and at low flux end ninety-three sources. The lines AC and BD have slopes -1.5 . If the universe were Euclidean and we accept the point B as correct, we find that we have an observed excess of fifty-three sources at five flux units. If the point A is correct, we have an observed deficit of some thirteen sources at the high flux end. Since the survey is over three steradians in the sky, the deficit in this latter case amounts to only of four to five sources per steradian! This can be easily accommodated in normal statistical fluctuation. The inconclusive nature of the present $\log N$ — $\log S$ data as far as cosmology is concerned, was emphasised by Kellermann in 1971 in the Warner lecture given to the American Astronomical Society.

These issues can be resolved if we are able to get red-shifts of these sources. They are mostly believed to be radio galaxies. If the red-shifts turn out to be large, Ryle will be proved right. If the red-shifts are not significantly larger than those for the sources in the first category, then we must agree with Hoyle that the test does not have any cosmological value. Another possible check on this issue would be the distribution of these sources over the sky. If the distribution shows anisotropy, then they cannot be very far away.

Clearly the quasar sources play an important part in the cosmological question, if it can be established that their red-shifts arise from the expansion of the universe. We have already seen reasons to doubt this. Recent work has revealed further evidence to support these doubts. For instance, Harlton Arp at the Hale Observatories has found cases where quasars appear to be visibly connected to galaxies—but where the red-shifts of the connected objects are quite different. There are quasars with multiple red-shifts posing further problems to the theoretician. At one time gravita-

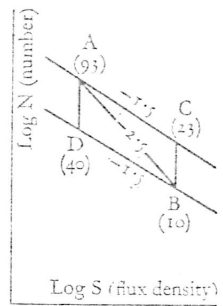


Fig. 10: Unidentified sources.

tional red-shift was considered to be an alternative cause of the quasar red-shifts. However, there is nothing structurally peculiar about the quasars to indicate the presence of very strong gravitational fields. Indeed, a fair assessment of the situation is that no conventional explanation of the red-shift seems to fit the bewildering new data.

I now come to what may be potentially the strongest evidence against the steady state model. In 1965, as Dr Sciama has graphically described, Penzias and Wilson of the Bell Telephone Laboratories detected isotropic radiation in the microwave region. Further measurements by others have confirmed the existence of this radiation at many other wavelengths in the microwave, and the existence of this radiation is usually taken as evidence for the hot big bang.

The main reason for this is as follows. In the hot big bang model, of the type imagined by Gamow in his problem of nucleosynthesis, there is primeval radiation of very high temperature. Subsequently this gets diluted by the expansion of the universe and we should now expect to see a remnant radiation of low temperature. The intensity of this radiation over different wavelengths should follow the well-known black-body distribution. The observed radiation does seem to follow this law at long wavelengths. If we extrapolate it to short wavelengths it corresponds to a temperature of approximately 3° Kelvin (-270° Centigrade).

How can the steady state theory defend itself against this observation? First, it is necessary to point out that observations have not so far established the black-body character of the radiation. The critical range of wavelengths over which the observations are necessary to settle this point is not accessible to ground-based instruments. One has to rely on rocket flights. The rocket flights first seemed to indicate radiation far in excess of that predicted by the black-body law. Subsequent observations, however, do not seem to be inconsistent with the black-body law.

If the law is not one of black-body radiation, then its association with the hot big bang is not so compelling, and one can look for other explanations of its origin. A strong indication that this radiation may be due to other astrophysical processes operating in the universe comes from the fact that its energy density is comparable to that of cosmic rays, starlight, magnetic fields and some other energy sources which have no direct bearing on the big bang origin of the universe. Thus, one could argue that this background could arise from individual sources distributed all over the universe—just as the X-ray background is believed to arise from X-ray sources.

There is some difficulty with this explanation, however. The observed background is very homogeneous—it shows no patchiness at all. This means, the sources of such radiation must be very numerous and evenly distributed—far more so than ordinary galaxies. So far no obvious candidates have appeared for such sources.

The observed isotropy presents problems for the big bang models also—which is a fact not generally known. The question arises in this case ‘Why should the radiation be so isotropic?’ In the early stages of the big bang the region of communication is very limited, and it is difficult to see why regions far beyond the limit of communication of one another should have exactly the same amount of radiation. Attempts to answer this question in more complicated versions of big bang have not so far succeeded.

I have so far argued rather like a defence counsel trying to get his client acquitted for lack of sufficient evidence. I now come to other considerations which are less equivocal than the observational data I have discussed so far, and which clearly point to the superiority of the steady state theory over the big bang cosmologies. My own interest in the steady state cosmology has been sustained over the years, not because of the uncertain observational situation, but because of a remarkable physical property the theory has. I shall attempt to describe this property below, omitting the quantitative details.

One of the most puzzling facts in our everyday experience is the asymmetry exhibited by time. We are always conscious of the time axis being divided into two compartments—the past and the future, and we talk of events ‘moving’ from the past to the future but not vice versa. This consciousness has come out of observing events which cannot be reversed. For example, when we place a hot body in contact with a cold one, heat flows from the former to the latter, but not vice versa. When we set an alternating current circuit in operation, it radiates electromagnetic waves and loses energy—it never gains it. If such events are filmed and the film is run backwards in time we see new events which are never seen in real life. All these experiences are summed up by the statement that time has an arrow, from the past to the future. Why does time have an arrow?

To answer such a fundamental question we may be tempted to turn to basic physical laws. Perhaps there is something in these laws that produces the time arrow. But this is not the case. The laws themselves make no rule of this kind, they are time-symmetric. In other words, the events seen on the film running backwards in the above example, must be possible

according to these laws. This makes the origin of a time arrow even more puzzling.

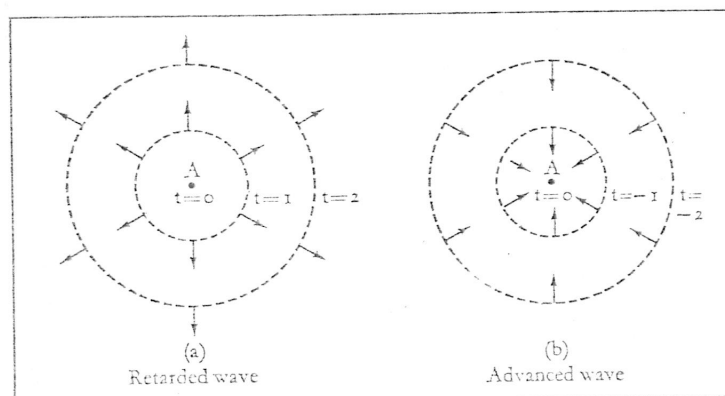
The usual way to get round this problem is to make an extra postulate which introduces this time asymmetry. The actual forms in which this postulate may be stated might differ somewhat according to different physicists—but the central idea is the same. Although this is a convenient device dealing with irreversible events it hardly takes us any further in understanding the origin of such events.

A more fruitful way is to look at such events in different branches of physics, and to see if there is any connection between them. The two examples described before occur in thermodynamics and electrodynamics, and are apparently not connected. I now give a third example which is even further apart from these two. This is the expansion of the universe. By saying that galaxies are moving further and further apart, we are introducing a time asymmetry into the picture. The reversed event, in which galaxies come closer and closer is not observed except in very isolated cases. Thus we have an arrow of time in cosmology, in addition to those in electrodynamics and thermodynamics described before. Are these arrows connected?

To a laboratory physicist, the idea that the arrows of time in electrodynamics and thermodynamics may be related, is not very unusual. But to him, to try to relate these two to the expansion of the universe, might seem fantastic. Yet, there exists a theoretical framework in which such a connection can be established.

To understand this connection, let us take a specific example—that of the alternating current circuit. Such a circuit radiates waves outwards. A simplified situation is shown in Fig. 11(a), where the source of the waves is at point A and the waves are spheres with A as centre. If we take $t = 0$ to indicate the time when the wave started outwards

Fig. 11: Retarded and advanced waves.



from A. After one second ($t = 1$) it will be in the form of a sphere of radius one light-second. At $t = 2$ it has radius two light-seconds and so on. A wave of this type is called the retarded wave, since it reaches a point away from the charge at a *later* instant.

The time reversed version of the retarded wave of Fig. 11(a) is clear in Fig. 11(b). Here the wave goes out from A at $t = 0$, but reaches a point away from A at an *earlier* instant. Alternatively we may argue that the wave is converging on A. Such a wave is called the advanced wave.

Now, Maxwell's equations, which give us the fundamental laws of electricity and magnetism, tell us that advanced as well as retarded waves are theoretically possible. Nature, however, seems to reject the advanced waves altogether. Why? It is not possible to answer this question without introducing some extra postulate.

There is, however, another way of describing electromagnetic theory which does not require an extra postulate but which brings in cosmology. This picture, known as *the action at a distance*, is in fact older than Maxwell's theory. In Maxwell's theory, two electric charges influence each other via the medium of a field. When one charge is set in motion it disturbs the field around it. This disturbance travels outwards (via retarded waves) and eventually reaches the other charge which then responds to it. In the action at a distance picture the two charges interact directly. In Fig. 12 there are two charges *a* and *b* moving in space and time. The influence of charge *a* from point A travels with the speed of light and reaches charge *b* at point B. The charge *b* reacts back in equal and opposite sense (according to Newton's third law of motion) along BA. Thus a retarded influence of *a* invokes an advanced response from B, and vice versa. The theory of action at a distance therefore treats advanced and retarded influences on an equal footing. In the figure, A is in interaction with two points on the world line of *b*, the point B is in the future and B' in the past relative to A.

The presence of signals going backward and forward in time is contrary to our experience and this has been one reason why this theory was never considered a serious rival of Maxwell's theory. It was not until 1945 that it was shown that this action at a distance theory can in fact be made to work. This remarkable work by two American physicists John Wheeler and Richard Feynman brought cosmology into the picture for the first time.

Wheeler and Feynman argued as follows. When we set a laboratory system A in motion, it interacts with the *entire universe* (see Chapter 8). Suppose we take the retarded wave

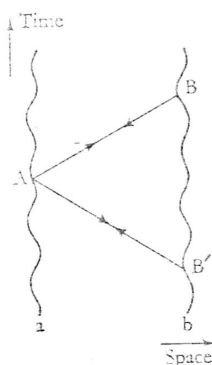


Fig. 12: Action at a distance.

moving outwards from A at time $t = 0$. It reaches a typical electrical charge B. As seen in the figure, this charge reacts via advanced waves which travel backward in time and arrive back at A at time $t = 0$. Notice that the reaction from B arrives at A instantaneously after the emission of the wave by A, no matter what the distance of B from A! Therefore all the electric charges in the universe can, and do, react to the motion of A. Wheeler and Feynman then proceeded to calculate the reaction of the universe as a whole to the motion of a single electric charge in a laboratory. The results of their calculation can be described symbolically as follows.

When a single charge is set in motion, it emits signals equally via advanced and retarded waves. We can describe this by saying that the net disturbance from the charge is given by

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

The reaction of the universe, as calculated by Wheeler and Feynman, was

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

The total disturbance leaving A is therefore

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

Thus we get only the retarded waves moving outwards, as observed. But, we also see that the retarded character arises because of the reaction R sent by the universe. This wipes out the awkward advanced part of F and augments the retarded part to the full observed value.

I have not so far said what model of the universe was used in this calculation. Wheeler and Feynman used the static Euclidean universe with a uniform distribution of electric charges. This model does not have a cosmological arrow of time, and this resulted in an ambiguity in the above result. Since the universe is time symmetric, we can reverse the direction of time in the above calculation and arrive at $T = (\text{Advanced})$! This case was eliminated by Wheeler and Feynman by using thermodynamic arguments. I do not propose to go into the details, except to point out that this line of reasoning results in linking the arrows of time in thermodynamics and electrodynamics, with cosmology playing a secondary role.

However, a more realistic calculation should involve expanding cosmological models. Calculations in such models have been performed by various people. Although details differ slightly, the broad conclusions are similar, and startling. In ever-expanding big bang models we end up with $T = (\text{Advanced})$, i.e., opposite to what is observed! In the steady state model we get the correct answer $T = (\text{Retarded})$.

Big bang models which eventually contract, yield ambiguous answers.

The reason for this result is not difficult to see. To get the correct answer, we need the reaction

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

from the future half of the universe. In big bang models which are ever expanding, the matter density diminishes to zero in the future and there is not enough matter to produce the required R . In the steady state model, continuous creation of matter ensures sufficient matter density to produce the correct R . In big bang models, the solution $T = (\text{Advanced})$ arises because there is enough matter in the highly dense past half of the universe to produce the opposite reaction

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

In the steady state model, on the other hand, the density is not allowed to be large at any stage in the past, and this solution is avoided. In general, models of continuous creation of matter (which need not be in strict steady state) fare better than those with a big bang creation.

If we adopt this reasoning we have a powerful test of cosmological theories. It has the merit of being clear cut and free from the type of observational uncertainties we have been discussing in the middle part of this chapter. Further, we are also able to see a little more clearly how the arrows of time in different branches of physics are related. The ideas here have recently been extended to quantum physics with fruitful results. A discussion of these, however, lies outside the scope of this volume.

To summarise, the steady state theory has been under attack ever since it was formulated in 1948. Some of the criticisms levelled against the theory have subsequently been withdrawn as being incorrect, like the Stebbins-Whitford effect. Others have inspired important theoretical developments in astrophysics like the theory of nucleosynthesis in stars. The theory has had its ups and downs, the worst period from its point of view being around mid-1965. At that time the observations of $\log N - \log S$ and the Hubble diagram for early quasars looked to be against the theory and the discovery of microwave background had just been made. However, its fortunes have picked up since then as some astronomers have begun to appreciate the uncertainties involved in the quasar observations and the fact that we still do not know the nature of quasar red-shifts. The microwave background remains a potential threat to the theory and it is vital to know whether it has the character of a black-body distribution. *Until the observational situation clarifies further it is*

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premature to write off the steady state theory. Certainly, in the attempts to account for such fundamental concepts as the arrow of time, the steady state theory succeeds admirably whereas the big bang cosmologies fail miserably.

Cosmology thrives on controversies and these debates will and should continue. My own belief is that the structure of the universe is much more interesting and sophisticated than that suggested either by the big bang model or by the steady state model.