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899th ORDINARY GENERAL MEETING

HELD IN THE LECTURE HALL OF THE NATIONAL SOCIETY FOR RELIGIOUS EDUCATION, 69, GREAT PETER STREET, WESTMINSTER, S.W.1, ON MONDAY, 19th MARCH, 1951.

PROFESSOR HERBERT DINGLE, D.Sc., A.R.C.S., IN THE CHAIR.

The Minutes of the previous Meeting were read, confirmed and signed.

The following election was announced:—Rev. Herman B. Centz, Fellow.

The CHAIRMAN then called on Professor W. H. McCrea, M.A., Ph.D., to read his Paper entitled "Continuous Creation."

CONTINUOUS CREATION

By PROFESSOR W. H. McCREA, M.A., Ph.D.

SYNOPSIS

Some of the difficulties and paradoxes of the previous theories of the expanding universe are reviewed. It is shown how attempts to overcome these difficulties appear to require the continuous creation of matter in the manner suggested by H. Bondi and T. Gold and by F. Hoyle. The new theory preserves the features of the previous ones that had already proved satisfactory. However, not only does it overcome the immediate difficulties which have been mentioned; it offers further the possibility of constructing a comprehensive cosmology. It is too early to estimate the successfulness of this possibility, but it appears to constitute the major reason for pursuing the new ideas.

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1. *Introduction.*

IT has recently been suggested that all the matter in the universe is the result of a process of *continuous creation* that takes place at all places and at all times. According to this suggestion, the matter is not infinitely old nor is it the result of one unique past event of creation. The process of continuous creation, if it takes place as suggested, thus determines the nature of the whole universe.

Certain problems concerning the large-scale behaviour of the universe appear to demand some new fundamental physical hypothesis in order to achieve agreement between theory and observation. H. Bondi and T. Gold have proposed one such hypothesis, what they term the "perfect cosmological principle", and F. Hoyle another, a certain modification of the formulae of relativity theory. Either of these is found, as an immediate consequence, to require the continuous creation of matter. The fact that this concept has thus made its appearance in such a technical setting probably accounts for its having provoked rather less comment than might have been expected. On the other hand, the fact that it does arise in this manner, rather than as being itself an isolated hypothesis, is an added reason for its serious consideration. And, of course, its possible fundamental significance is widely appreciated.

The present paper is an attempt to review the reasons for suggesting that the process does take place, the characteristics of the suggested process itself, the way in which these characteristics would determine certain properties of the astronomical universe, and the possibility of using the observable features of the universe to discover whether the process does actually occur. In conclusion, the history of the subject is briefly sketched. No attempt is made here to treat any possible philosophical implications.

The reader might suppose that a process which corresponds to what seems such a revolutionary concept must have simple and obvious consequences both theoretical and observational. It may come as a surprise that somewhat lengthy discussions are needed in order to discover what the consequences are and how they differ from those of traditional views. That this is so can be taken as indicating that, in the present state of development of physical science, the concept is actually not so revolutionary as it at first appears. It will also be seen to mean that no definite decision can yet be reached as to the validity of the concept.

The present situation appears to be this:—When we apply current physical theory to the phenomena of the universe on the largest scale on which we are at present able to observe it we encounter certain difficulties. It seems that these can be overcome by hypotheses which require a process of continuous creation to occur in nature. It then turns out that the occurrence of this process would provide quite naturally the hitherto undiscovered connexions between various other cosmic phenomena. Therefore, whether or not the original reasons for suggesting the process are judged to be compelling, the general coherence it would give to cosmological theory is the strongest reason at present for believing that it does occur. Nevertheless, further progress in theory and observation is needed in order to provide crucial tests.

2. *Expanding Universe.*

On the largest scale on which it has hitherto been possible to study the universe by astronomical observation, the "units" into which it is found to be organized are *galaxies*. These, which include the objects more familiarly known as "spiral nebulae", are systems each of which is believed to be comparable in size and in the amount of its material to the particular system of which the Sun is a member. The latter system is known as *the* Galaxy (or the "Milky Way"). Most astronomers have for many years believed that effectively all the matter in the universe is concentrated into these galaxies.

The number of observable galaxies is very large. It is estimated, for instance, that a photographic survey of the sky now being made with the Palomar Schmidt Camera will record 10m (m = million) of them. Surveys made in the past have been interpreted as showing that, on a large-scale statistical basis, they are distributed uniformly through space.

By about 1930 spectroscopic evidence had been accumulated whose only possible interpretation in accordance with known physical principles showed that all other galaxies are receding from our own (and its immediate neighbours) with speeds proportional to their distances. The empirical result, known as "Hubble's law", is that a galaxy whose distance in millions of light-years is D has an apparent speed of recession of about $100D$ miles per second. The new 200-inch Hale Telescope can photograph galaxies out to an estimated distance of 1000m light-years: if Hubble's law holds for these, they must be receding with apparent speeds of about 100,000 miles per second.

A simple inference from Hubble's law, if the interpretation of the evidence in terms of actual motions is correct, is that every galaxy must be receding from every other, and not merely from our own, according to the same law. This is the phenomenon of the *expansion* of the universe.

Now up till about 1930 it had been generally supposed that the universe as a whole must be in a mechanically *static* state. Of course, well-established physical principles such as the second law of thermodynamics demanded that the contents of the universe should be evolving in some manner. But it was not generally conceived that the total amount of material in any large tract of space could change progressively with time: whither, in fact, could the material go? By 1930, however, mathematicians had shown that the accepted laws of mechanics and gravitation do not in fact allow the universe to be static and that, as a *theoretical* necessity, it must be expanding (or contracting). As to whither the material goes in the process, relativity theory describes the state of affairs by saying that space itself is expanding. But, for our purpose, we may equally well think of the matter as receding *in* unbounded space.

Thus both observation and theory led almost simultaneously to the same remarkable conclusion and seemed to leave scientists with no alternative but to accept the astonishing concept of the expanding universe.

Now if the galaxies are receding with speeds proportional to their distances, and if each galaxy has always had the same speed as it has now, then it would follow that every galaxy in the universe was at zero distance at one and the same particular epoch in the past. A simple application of Hubble's law would show that this occurred about 2000m years ago. Even if the calculation is carried out making full allowance for the mutual gravitation of the galaxies and its effect upon their motion in the past, and whether we treat space-time and gravitation according to the methods of classical theory, general relativity theory, or of kinematic relativity, we reach effectively the same conclusion. According to any of these theories, *the universe must have started upon its career of expansion about 2000m years ago and must have been initially in a state of enormously greater congestion than it is now*. Since the theories had to view the start of the expansion as a singular epoch and since they could attach no meaning to events earlier than this, the conclusion could be expressed by saying that the universe was *created* 2000m years ago, that it was then highly congested, and that it has been dispersing ever since.

On the whole, astronomers were at first favourably inclined towards this conclusion. For ages of a few thousand million years were being inferred independently for a number of astronomical systems. Studies of radioactive substances or their products give 2–3 × 1000m years for the age of the oldest rocks on the Earth and (provisionally) up to about 7 × 1000m years for the ages of meteorites. From this and other evidence, the age of the Solar System is generally believed to be between 3 and 6 × 1000m years. In so far as it was then possible to estimate the ages of the stars, these too came out in certain cases to be of the same order of magnitude. Again, our Galaxy was known to be rotating about its centre, and it was calculated that certain observed features could not have survived more than 10 to 15 rotations; at the relevant distance from the centre, this would mean 2–3 × 1000m years. And several other cases could be mentioned.

Though some of these estimated ages of systems in the universe were rather more than the estimated age of the universe itself, what seemed significant was that they were all of the same order of magnitude. It was tempting to believe that any incompatibilities between the results would be resolved by taking account of a speeding-up of some evolutionary processes in the early stages when the universe was so much more congested than now. So it seemed that the theory of the expanding universe supplied the general explanation of the order of magnitude found for all these "ages".

Another consequence of the theory requires mention. If Hubble's law, or anything like it, holds for all galaxies, then those at some particular distance R would be receding with the speed of light. (Hubble's law would give $R = 2000$m light years, approximately, *i.e.* about twice the estimated distance at which galaxies can be photographed with the biggest existing telescope.) But an object receding with the speed of light would be invisible, since the Doppler effect would reduce to zero the apparent intensity of its radiation. Any galaxy further away than distance R would also, of course, be unobservable. There would in fact be no physical meaning to be assigned to the existence of such a galaxy. Therefore, the distance R affords a natural frontier to the observable universe.

A more technical discussion according to relativity theory might express the conclusion in a different form, but the physical interpretation would be effectively the same.

This again is a satisfactory outcome of the theory. For it at once explains why we do not observe a bright background to the sky. Any "static" theory, on the other hand, suggests that there should be such a background supplied by light continually arriving from distant parts of the universe or by light that has travelled more than once "round the universe".

3. *Criticism of "capital" theories of the expanding universe.*

I shall call any theory, such as that just described, which supposes all matter to have existed in one possible form or another throughout the lifetime of the universe, a *capital* theory.

To my mind, the most serious criticism of the capital theories of the expanding universe is that they have explained so little. I shall return to this in section 10.

However, the most immediate difficulty is that no way has in fact been found of reconciling the estimated age of about 3000m years for the Earth and of about 5000m years for the oldest stars with the conclusion that the age of the universe itself is only about 2000m years.

Moreover, when Hubble attempted to match all the observational data concerning the apparent motion and distribution of the galaxies with the properties of the "model" universe calculated from relativity theory, he found that theory and observation could not be brought into agreement.

These difficulties have been appreciated for about fifteen years. It is not considered by those qualified to judge that they can be ascribed to the uncertainties in the observational data or in the calculations. Drastic hypotheses designed to overcome the difficulties have been tentatively proposed by Dirac, Hubble and Milne. But none of these has gained general acceptance and none apparently would meet the general criticism I have mentioned.

There is another objection. Observations such as those yielding Hubble's law constitute a "snapshot" of the universe as seen at our own epoch. According to the capital theory of the expanding universe a "snapshot" taken, say, 1000m years hence would be different. Any individual galaxy would be receding with a smaller speed than now on account of the gravitational attraction of the rest of the universe having retarded its motion during the interval. In particular, a galaxy now seen to be moving with almost the speed of light would then be moving with a speed V, say, less than that of light. But if our snapshot does show galaxies receding with all speeds up to that of light then we should expect one taken by an observer 1000m years hence also to do so. Therefore all the galaxies he would see having speeds greater than V *must have entered the observable universe* between now and the time of his observation. In other words, galaxies are being *created* at the frontier of the universe.

This is a simple description of what is in fact found to be a property of the "model" universes provided by the theory. We have thus the paradox that a theory which does not profess to treat of creation, demands not only creation at a singular epoch in the past but also continuing creation at all epochs at the frontier of the universe in space. Thus a capital theory of the expanding universe demands that the total amount of "capital" should increase even though it becomes more dispersed.

4. *Continuous creation.*

If, as we have seen, the capital theory allows too short a past duration of the universe, we must now enquire how that duration could have been extended.

To consider the extreme possibility, we ask what would be required in order to ensure that the universe, instead of changing apparently too rapidly, should not be changing at all.

We shall, in fact, make the working hypothesis that the universe is in a statistically *steady state.* Having seen the implications and consequences of this hypothesis, we shall ask if they indicate any process whose existence would, conversely, ensure a steady state or some state of not too rapid change.

The universe is said to be in a steady state if, on the large scale, it looks the same at all epochs. It does not mean that any particular galaxy must always look the same. Also it does not mean, as will become clear, that the universe is "static" in the sense previously used. In fact, we use the word "steady" in the sense in which we might say that, as shown by the vital statistics, the population of a certain country has been "steady" for several years.

We continue to accept and use the same *observational* data as before concerning the expansion of the universe.

We consider the part of the universe within any fixed distance D million light-years of our Galaxy, where D is large enough for this to contain a large number of galaxies. Then, according to the hypothesis, this region must always contain the same amount of matter. But, according to the observed recession of the galaxies, matter is flowing out of this region, and according to our hypothesis it must be doing so always at the same rate.

Clearly these two conclusions are compatible only if fresh matter is appearing in the region at the same rate as matter is flowing out of it. This fresh matter cannot come from outside the region. For no in-flow of matter is observed. In any case, an in-flow which would balance the out-flow at all distances would establish our Galaxy as the unique centre of the whole universe, and would have the absurd consequence that the motion of matter at the remotest distances would depend solely upon its position relative to ourselves. Consequently, we describe the fresh matter as being *created* inside the region.

A short calculation on the basis of Hubble's law shows that the required rate of creation is for any region approximately ($\frac{3}{2,000,000,000}$ × matter present at any time) per year.

Another way of stating this result is to say that the rate is the same as if all the material in any region were entirely replaced by new material once in about 700m years. In round figures, which are all that we can use here, we may call this 1000m years.

If we take what the astronomical evidence would seem to give as an upper bound to the average density of matter in the universe, this rate is the creation of no more than one gramme of matter in a volume equal to that of the Earth in a thousand million years.

This rate of creation is far too small to be observed directly. It would have no effect upon laboratory physics. Indeed, it could have no direct effect even upon most of the problems of astronomy; it could be significant only for problems of long-term evolution in the Galaxy and for the study of the universe of galaxies.

5. *Resulting description of the universe.*

We now consider more fully some general features that would be possessed by the universe if it is in a steady state.

Every observer would see the universe as expanding away from himself in such a way that matter is continually disappearing at the frontier. For the previously described gravitational slowing-down could not occur in a steady state. It is to be noted, however, that the disappearance would not look like the annihilation of matter at a definite boundary: owing to the increase of speed of recession with distance and the consequent weakening of the radiation received from them, the observer would most naturally describe the remotest galaxies as "receding to infinity".

Nevertheless, however long the observer continues to observe he would see the same amount of matter in the universe as a whole, or, apart from random fluctuations, in any region which he would describe as a "fixed" part of the universe. In passing, we may therefore remark that, on this view, there is conservation of mass in every fixed part of the universe and in the universe as a whole; *i.e.* unlike the capital theory, it requires no *net* creation of matter to be proceeding in the universe. Since the steady state hypothesis is only provisional this point should not be overstressed except as showing that the consequences of the views we are developing may be less, and not more, extraordinary than those of the older views.

Further, the observer would see the matter to behave on the average always in the same way. So, since he sees some galaxies receding out of any region he must also witness the birth of other galaxies in that region. Now, our conclusion that the rate of creation is such that the matter in the region could be renewed in about 1000m years does not mean that no particular matter remains in the region longer than this. The matter leaving in any interval includes some created during the interval, while that remaining includes some that was there at the start of the interval. Our conclusion means that the *average age* of matter or of galaxies in any region is about 1000m years.

On any conception of the birth and evolution of a galaxy we should not expect it to count amongst the observed galaxies until its evolution has proceeded for a considerable time. The average age of *recognizable* galaxies must therefore be considerably more than 1000m years.

The hypothesis that the universe is in an unchanging steady state might have been thought to be equivalent to assuming merely that it is infinitely old. This is not the case. In fact, it gives for the average age of what is observed the same order of magnitude as does the capital theory. Thus the *generally* satisfactory nature of this feature may equally well be claimed for the new theory. What the hypothesis enables us to avoid is the conclusion that everything we see dates from the same singular past epoch. But it actually denies the conclusion that we can observe anything that is infinitely old.

The age of the observable universe does not increase indefinitely simply because, on account of its recession, any other galaxy (save one bound to our own by gravitational attraction) cannot remain indefinitely within the observable universe.

On the other hand, *the age of an observer's own particular galaxy does increase indefinitely.* No observation, and no form of the theory of the expanding universe, suggests that the mutual recession of different galaxies is accompanied by the dispersal of the material of a single galaxy. All material that belongs to a galaxy is to be considered as permanently held together by its own gravitational attraction.

In particular, therefore, the hypothesis removes any limitation upon the age of our own Galaxy. That age has to be discovered from the Galaxy itself. It no longer has to be thought of as being determined or restricted by anything we call the "age of the universe." This is how, perhaps less obviously than might have been expected, the hypothesis resolves the age-paradox produced by earlier theories.

6. *Creation process.*

The preceding discussion requires that, averaged over long periods of time and large regions of space, the rate of appearance of fresh matter should be constant. So far as we have gone, it would make no difference whether, at the one extreme, fresh galaxies are created entire, or, at the other, the fresh matter makes its first appearance in some diffuse form throughout all space and is thence gradually gathered up into galaxies.

There are several grounds for investigating the latter possibility:— (*a*) It is essentially the simplest that we can conceive. (*b*) The alternatives would tend to restore for each galaxy separately the sort of difficulty previously encountered for the system of galaxies. (*c*) There is already good reason to believe that a galaxy starts as a gas-cloud and that stars are formed from the gas by processes of condensation and accretion; it is more natural to believe that the galaxies themselves are formed analogously by condensation from a still more extensive gas-cloud than that radically different concepts are needed to account for them. (*d*) It does offer the possibility of tracing the evolution of cosmic systems back to the simplest possible beginnings instead of simply having to accept their existence in some already complex state.

We therefore make the tentative assumption that the newly created matter appears *uniformly* (in a statistical sense) *throughout all space.*

This implies that a unit of newly created matter should be nothing more complicated than a single atom, and moreover the simplest sort of atom, *i.e. a hydrogen atom.* For anything more complicated than this could be ranked as some form of "condensation."

It does not signify, for our purpose, whether we suppose the hydrogen atoms to appear first in the form of complete atoms, or of neutrons, or of protons and electrons separately. Other "elementary" particles might make temporary appearances without affecting the results.

7. *Formation of galaxies.*

The *tendency* of the recession of the galaxies is to leave more and more space devoid of galaxies; the *tendency* of the postulated creation process is to occupy this space with a tenuous uniform distribution of hydrogen gas.

Now it was long ago pointed out by Jeans that a uniform distribution of gas is unstable towards certain small disturbances of its uniformity. We can describe the effect by saying that a uniform gas in otherwise empty space has an ever-present tendency to "clot" on account of this phenomenon of gravitational instability, as it is called.

Combining this effect with the two tendencies already noted, we obtain the following picture of the happenings in any large region of space. Scattered through the region are a number of condensations of matter which we can regard as being already well-defined galaxies. Spread through the whole region there is the gas which has not yet gone to form galaxies and which tends to be endowed with uniform distribution. In any locality not predominantly under the influence of a particular galaxy, the combined effect of the galaxies is merely to disturb the uniformity of the gas and so to promote the formation of "clots"; these we envisage as incipient new galaxies. In the vicinity of an already well-defined galaxy, on the other hand, the gas tends merely to be drawn into the galaxy by its gravitational attraction. The result is that such a galaxy is continually growing by accretion. This is, of course, only an advanced stage of the "clotting" or "condensation" process.

Such, briefly, is the conception we attain of the birth and growth of galaxies, the process as a whole being never nearer to completion at one epoch than at another.

Granting the creation process, the rest is not purely speculative. Though on a different scale, we have *within* our Galaxy more or less direct evidence of the operation of the other basic processes. If, in the description of their operation, for "stars" we read "galaxies" and for "interstellar matter" we read "intergalactic matter", we do obtain essentially the picture of the evolution of galaxies as described above. (The analogy is to be taken only in general terms: the methods of operation of the basic processes must differ considerably.)

According to this picture, the galaxies produced would naturally tend to be uniformly distributed through space. But a uniform distribution of galaxies would be unstable for the same reason as a uniform distribution of gas. Hence the galaxies would themselves tend to "clot" or "cluster". Now this is what is observed. The statistically uniform distribution of the observed galaxies is claimed to hold good only on a very large scale. Viewed in rather more detail, it is seen that some galaxies are scattered through space in an apparently random fashion while others do form definite clusters of anything up to several hundred members.

No full mathematical treatment of this part of the subject has yet been given. (Such a treatment should, of course, treat the "condensation" and "clustering" processes as acting simultaneously.) For this reason one does not care to have to discuss it very much at this stage. But it will be seen that what we are primarily concerned about is the fact that the treatment is possible in principle. Provided the creation of hydrogen atoms is admitted as supplying the raw material, it would trace back all the large-scale features of the universe to the occurrence of this one rudimentary process, using otherwise only well-established physical theory.

Though the proper mathematical treatment is lacking, Bondi and Gold, Hoyle, and the present writer have called attention to certain "order of magnitude" estimates which do in fact show that the quantitative results may prove satisfactory. (References given in section 12.)

8. *Evolution of the Galaxy.*

It has long been realized that hydrogen is the most abundant element in the universe. But it has only recently been appreciated how great its preponderance is. Reckoning by numbers of atoms, the empirical evidence is that probably less than one per cent of the material in the Galaxy is neither hydrogen nor helium, possibly about one per cent. is helium, and all the remaining 99 per cent or thereabouts is hydrogen.

This in itself suggests that hydrogen is the parent element of all others. This view is supported by the now generally accepted fact that the stars generate the bulk of their radiation by the transmutation of hydrogen into helium, so that hydrogen is the essential fuel of stellar luminosity. Acceptable conclusions follow from the assumption that stars are initially formed of pure, or almost pure, hydrogen. The view in question may be said, in fact, to have been held by many astrophysicists for the past twenty years. The creation hypothesis in the form here discussed may be regarded as providing a possible basis for this view.

The alternative on a capital theory would be to suppose that the material at or shortly after the epoch of creation consisted almost entirely of hydrogen. But this would mean that the universe has been consuming its stock of hydrogen ever since and it would be difficult to account for the fact that there is still so much remaining. According to the continuous creation theory, however, a galaxy is continually growing by accretion and, since the accreted material consists of hydrogen, the persisting abundance of this element is explained.

If this is granted, existing knowledge of the evolutionary processes going on within the Galaxy is probably sufficient to enable a theoretical estimate to be made of the consequent relative abundances of the chemical elements at any particular epoch.

The purpose of this section is to indicate that processes within a galaxy, and so, after what has already been said, all astronomical processes can in principle be incorporated in a single coherent system of cosmology based upon the continuous creation of hydrogen atoms.

9. *Construction of a cosmology.*

The accompanying table is an attempt to summarize the construction of a cosmology of the sort just indicated.

In order theoretically to predict the mean density of matter in the universe we should require an appropriate field-theory as discussed by Hoyle (*Monthly Notices, R.A.S.*, *108* (1948) 372, *109* (1949) 365 and McCrea (*Proc. Royal Soc. A.* (1951)). If for the moment we take say the rate of recession of the galaxies to be supplied empirically, then everything else in the table appears to be deducible *seriatim* using only known physical theory.

As already stated the programme as indicated has not been carried out in any but a fragmentary manner. For instance, what Hoyle in his *Nature of the Universe* calls the "new cosmology" can be regarded as a preview of some parts of the programme. His discussion encourages a favourable view of its possible success.

It cannot be asserted that no such programme could be based upon a capital theory. But it is difficult to see how this would be done, and nobody has yet done it (except in regard to a small proportion of the items in the Table and then apparently without definite success).

10. *Conclusions*

We are now in a position to state some of the main conclusions of the discussion.

(1) It does appear that the creation theory can in principle predict effectively all the properties of the astronomical universe from exceedingly simple premises.

Construction of a Cosmology for a Universe in a steady state

	Phenomenon	Theory required for predicting the phenomenon.
1.	Rate of creation	[Postulated]
2.	Mean density of matter in the universe	Field-theory
3.	Rate of recession of galaxies Size and mass of observable universe Mean age of galaxies	Consequences of 1, 2
4.	Mean distance between galaxies	Theory of gravitational instability (adapted for application in expanding universe)
5.	Mass of galaxy as function of its age	Accretion theory
6.	Ratio of galactic to intergalactic matter	Consequence of 2, 5
7.	State of rotation of a galaxy	As in 4, 5
8.	Clustering of galaxies	As in 4
9.	Chemical composition of galaxy as a function of its age	Consequence of 5 and theory of stellar evolution
10.	State of Galaxy Ratio of stellar to interstellar matter Numbers of stars of various sorts etc.	Consequences of 5, 9 and astrophysical theory.

For the most part, we do not yet know whether it will give quantitatively correct results.

Whether it will or not, we contrast it with the capital theories. These can be said to have predicted the expansion of the universe and then proved completely barren of further progress. It is truly astonishing that the discovery of such a fundamental feature of the universe as its expansion has hitherto helped to explain practically none other of its properties.

In so far as the creation theory can yet be said to have a definite formulation, that formulation may not prove to be correct. But, if not, the situation I have tried to state is such that cosmologists will be almost bound to keep up their attack along generally similar lines; it now appears extremely unlikely that they will ever withdraw again to the position they were in before the creation theory was proposed.

(2) The creation theory is found to require a rate of creation that we can never observe directly. Nevertheless, the theory is capable of observational test just like any other. If its predictions of the phenomena listed in the table are found to be in quantitative agreement with observation, this will be "verification" in the accepted sense.

It is important to see that it ought to be possible to discriminate observationally between predictions due to the two kinds of theory. For the capital theories require all galaxies to be of the same age at the same cosmic epoch. Therefore they require that remote galaxies should *all* appear younger than our Galaxy simply because the time taken by their radiation to reach us means that we see them at an earlier cosmic epoch than our own. On the other hand, according to the creation theory, when our own Galaxy was born there must have been some much older galaxies in its cosmic vicinity. Owing to the recession, these must now have become remote and, of course, still older. But meantime new galaxies must have been born in *their* vicinities. Therefore remote galaxies should include some older and some younger than our Galaxy. If we can discover some observational criterion for the age of a galaxy and if this latter inference can then be checked it will give a fairly direct verification of the creation theory.

(3) This brings us to the conclusion already stated in the first section—that there is without doubt a case to be considered; but that the evidence is not yet sufficiently complete to obtain a verdict.

11. *Further considerations.*

There remain several considerations each of which could be enlarged upon but which have here to be mentioned very briefly.

(1) The approach we have followed has been of the same general character as we might adopt for any other general problem of astrophysics. It would not be unfair to compare it with discussions that were going on some twenty years back about the source of *stellar energy.* These latter were speculative and inconclusive at the time, but they helped to clarify the issues, so that when, several years later, an acceptable solution of the problem was presented it was possible to recognize it as being acceptable. Further, when this solution was found, it came from natural developments in atomic physics, but it is generally admitted that the discussions of the astrophysical requirements had played a significant part in stimulating these developments.

Astrophysicists and cosmologists have now proceeded to the next stage and are now asking about the source of stellar *matter* and, indeed, of all matter. Clearly, atomic physics is not yet ready with a complete solution. But it is significant that cosmology has reduced its problem to one of *atomic* physics, for the creation process it believes to be required is one of single elementary particles. Once again astrophysics may have indicated a needed advance in pure atomic physics.

(2) We have perhaps over-stressed the considerations relating to *continuous* creation. As Hoyle has pointed out, were it possible to conclude that the creation of matter was over and done with very much longer ago than several thousand million years, then the foregoing discussion might be taken to show that the physics of the creation process can have little significance for the various astronomical systems known to us; conversely, the study of these systems would tell us little about the creation process. The whole trend of the discussion is, however, to show that whether we are ultimately led to adopt a "capital" theory or a theory involving continuous creation, a knowledge of the physics of the creation process, *i.e.* the physical nature and physical state of newly created matter, now seems to be essential for the construction of a cosmology.

(3) The significance of our basic requirement being an *atomic* process is very profound. For it now appears that a knowledge of this process may well provide the long-sought connexion between atomic physics (quantum theory) and large-scale physics (relativity theory). This is a far-reaching question. All that

can be said here is that the indications provided by the continuous creation theory are promising.

(4) Most of our discussion has dealt with a universe which is supposed homogeneous in space and "steady" in time. In the past, writers on cosmology have elevated these suppositions to the rank of "cosmological principles". I think it is preferable to regard them merely as providing in the first instance the simplest cases for mathematical treatment, and, if the results of such treatment are found plausible, in the next instance as providing a first approximation applicable to the part of the universe in space and time which is accessible to existing means of observation.

12. *Historical survey.*

This is not intended to be complete. Indeed the physical principles which may be violated by a possible continuous creation of matter have been formulated only in comparatively modern times, and indeed I doubt whether they ever have been precisely formulated so as to apply to the universe "as a whole." It is therefore probable that many cosmological speculations of the past would on analysis be found to suggest continuous creation.

In recent times, apparently the first definite suggestion was that of J. H. Jeans (*Astronomy and Cosmogony* (Cambridge 1928), p. 352) who briefly considered the possibility that the centres of galaxies might be places where matter is "poured into our universe." The general possibility that the number of protons and electrons in the universe might be increasing with time was tentatively suggested by P. A. M. Dirac (*Nature 139* (1937), 323) but was not maintained in his later work on cosmology. Dirac's ideas seem, however, to have been the stimulus for a form of the theory of continuous creation developed by P. Jordan (*Die Herkunft der Sterne* (Stuttgart 1947); *Nature 164* (1949) 637). This theory requires the spontaneous appearance of quantities of matter of stellar dimensions. While based upon arguments having considerable physical interest, it is scarcely in conformity with current trends in astrophysics. In 1940 R.O. Kapp (*Science versus Materialism* (London 1940), Ch. 26) independently raised the question of the possibility of the continuous creation and disappearance of matter in the universe, giving a stimulating review of the general considerations involved. My attention has also been called to Sir Robert Kotzé's book, *The*

Scheme of Things (London, 1949), in which he presents a hypothesis of continuous creation or re-creation, but without discussing physical evidence or physical arguments in support of his contentions.

The theory in the form discussed in the present paper was originally presented, almost simultaneously, by H. Bondi and T. Gold (*Monthly Notices, R.A.S. 108* (1948), 252) and by F. Hoyle (*ibid.*, 372). It is highly significant that the very different approaches they adopt led them to very similar conclusions. The cosmological and astrophysical implications have been discussed in further writings by Hoyle (*Monthly Notices, R.A.S. 109* (1949), 365; *Nature 163* (1949), 196; *The Nature of the Universe* (Oxford 1950)) and I have to acknowledge my indebtedness to his ideas at almost every stage in my presentation. I have previously discussed some aspects of the problem in *Endeavour 9* (1950), 3 and have recently shown how an interpretation in conformity with orthodox relativity theory appears to be possible (*Proc. Royal Soc. A.* (1951)).

A very general survey of the whole situation in modern cosmology has been given by H. Dingle (Norman Lockyer Lecture 1949, *Advancement of Science 7* (1950) 3).

Discussion.

The Chairman (Prof. Herbert Dingle) said : The idea of the continuous creation of matter seems to be regarded in some quarters as highly revolutionary, if not essentially unscientific, and I think Professor McCrea has done well to point out that it is not essentially different in character from ideas with which the scientist has long been familiar. The fundamental particles that are assumed spontaneously to appear must not be thought of as small bits of ordinary matter ; they are conceptual entities to which are assigned whatever conceivable properties are necessary to enable us to explain what we observe, regardless of whether those properties are familiar or not. Thus, it is meaningless to speak of the colour of one of these particles, or of its temperature or its velocity at a given place, or of many other qualities which we quite properly associate with a bit of observable matter, however small. In particular, we cannot count the particles as we count ordinary objects—they obey, we say, different statistical rules—and their "number" does not mean exactly the same as the number of persons, for example, that will be revealed by the forthcoming census. We have, in fact, to form for ourselves the conception of number which we can apply to them in order to enable them to fulfil their function of explaining observations, and what the new idea suggests is that that conception should include the property of variation with time. This may turn out to be right or wrong, but it is quite a normal scientific hypothesis. Like all such hypotheses it will stand or fall by its consistency with observations that we can make here and now: that remains the final court of appeal in all science.

There are many points in Professor McCrea's interesting lecture on which I should like to comment, but I must confine myself to one or two. I do not think he does full justice to the "capital" theories when he accuses them of involving creation of matter at the boundary of the universe. Such theories do not necessarily require that the speed of a galaxy decreases with time; it might increase quite consistently with the conservation of capital—indeed that, I think, is what has usually been held—and in that case this objection does not stand.

Another point of interest that arises from the scheme that Professor McCrea has put before us is the question concerning what we are to mean by the word "universe." He has identified the universe with what is observable now, and the galaxies that have passed beyond the bounds of observability are not included in it. Hence the universe is definitely limited in its spatial extent to a sphere with a roughly assignable radius. But he makes no such limitation with regard to time. One would have thought that on this principle time began when the oldest galaxy now visible was born, but an eternal past and an eternal future are contemplated in this theory. The whole question of the relation between "existence" and "observability" requires more attention, I think, than it is given here.

Finally, according to the picture we have been given, a galaxy is always acquiring new hydrogen and simultaneously transforming its stock of hydrogen into heavier elements; there is no provision for the loss of matter from a galaxy. Hence each galaxy grows continuously richer in all the elements as time goes on. If we are to contemplate an eternal past, then we cannot help contemplating galaxies containing amounts of matter ranging from a rather indefinite minimum up to infinity. What distribution of galaxies would be visible at any moment from such a one as ours would seem to depend on what happened to be in our neighbourhood when our galaxy was born and what happened to have been removed from the "universe" by recession since its birth. This, I suppose, would be largely a matter of accident, but one would expect a very large range of size, with the average size getting greater at greater distances. In fact, however, to a first approximation all the visible galaxies appear to be roughly equal in size. Indeed, if this is not so, the accepted law of the expansion of the universe breaks down, for the distances of most of the galaxies are determined on the assumption that their size is uniform. There is a problem here also, I think, which needs more attention than it has been given.

It will be clear that whatever else may be said of this theory, it excels in raising questions for discussion. The meeting is now open for such questions.

Dr. R. J. C. HARRIS said: Since the evidence for the expansion of the Universe appears to rest almost exclusively upon the red-shift of light received from the galaxies and the application to this of Doppler's Effect, is it not possible that there could be an alternative explanation for this reddening which does not involve the recession of the light source from the observer?

Mr. W. E. FILMER said: The conception of an expanding universe and the theory of continuous creation appear to me to involve more difficulties than they seek to solve. They appear to violate those generally accepted laws which we have always considered governed the universe, and consequently a number of amendments to these laws have to be postulated.

The conception of continuous creation is first of all by definition contrary to the law of the conservation of matter. Further, since matter and energy are regarded as of fundamentally the same nature, the law of conservation of energy is likewise violated.

The conception of an expanding universe involves an amendment to the law of gravity which hitherto has only included a force of attraction. Now a force of repulsion which increases with distance must be postulated in order to account for the nebulæ receding from one another with ever-increasing velocity. This, again, leads to further difficulties with the law of conservation of energy: for, consider any large but finite volume of space, matter is continually moving out through the boundary of this volume with some finite velocity by virtue of which it possesses kinetic energy. Thus, kinetic energy is perpetually passing out through the boundary of any given volume, and it is difficult to understand where all this energy comes from. The question becomes even more difficult when we consider the whole observable universe, where it is postulated that matter is continually passing out through its frontier with the velocity of light. According to the Einstein formula the kinetic energy of a body moving with the velocity of light becomes infinite. Hence it would appear that an infinite amount of kinetic energy is perpetually passing out through the frontier of the observable universe. Where does all this energy come from?

It would be interesting to have Prof. McCrea's explanations of these difficulties. Do they not involve a whole series of amendments to the laws of nature which have to be postulated to account for one simple observed fact, namely, the red-shift in the spectra of distant nebulæ? Would it not be simpler, and therefore nearer the truth, to suppose that the propagation of light is subject to a dissipating force analogous to friction, whereby the energy content of a quantum of light is gradually dissipated in its passage through space, thus leading to a corresponding increase in the wave-length associated with this quantum? Such an hypothesis would appear to be in line with such accepted principles as those of entropy and the second law of thermo-dynamics.

Mr. F. W. Cousins said: Continuous creation, the Professor tells us in his synopsis, is born from the paradoxes associated with the expanding universe. Hoyle and others have suggested that it is preferable to the idea of creation all in one "big bang"; while Professor Dingle, in his Norman Lockyer lecture, November 22nd, 1949, said: "So far as I can see, the hypothesis of continuous creation of matter is the only one that allows us to admit a one-way direction in cosmical processes without demanding a special act of creation or its equivalent at an arbitrarily selected moment of time."

Here, then, we have the setting—a possible dislike of cosmologists for a creation in the Genesis sense of the term or an attempt to overcome the paradoxes of an expanding universe, itself not an established fact. It must be pointed out that the red-shift is considered as a Doppler effect only on the basis that the light from distant nebulæ is the same as light in our laboratories and it may well not be the same. Zwicky has suggested a "gravitational drag of light" since light has mass and passes matter in space—while MacMillan has pointed out that loss of energy of light photons would, as in the case of the gravitational drag, cause a decline in the frequency of the radiation and thus a reddening during transit. Hubble has been led to dispute the validity of the concept of expansion based on red-shift and he is no mean authority and fully aware of the difficulties.

The Professor has some dislike, it seems, for a static universe; and in 1930 he tells us mathematicians required the universe either to expand or to contract—why, may I ask? Is it not an over-simplification to state this so? Did not De Sitter construct a static world-model which satisfied the Einstein laws of world gravitation? The more one reads of world-models and mathematicians in dispute over them, the more one inclines to the view that world models are as women's fashions—ephemeral things, which have their day and gracefully depart. The objection to a "static" theory at the end of paragraph 2, regarding a bright background to the sky, was raised by Olbers in 1826 but it can be overcome by assuming that the stars in the remote regions of space are much fainter than those in our neighbourhood—or that light is gradually absorbed during its passage through space.

The paradox on pages 109 f., the estimated age of the Earth as 3,000,000,000 years and an age of the universe of 2,000,000,000 years, is, to my mind, due to the view expressed on page 108, lines 8–26, viz., that expansion of the universe puts creation at 2,000,000,000 years ago; but it is purely a legacy of the expansion concept and if this is considered untenable, then the estimate of 2,000,000,000 years is untenable with it.

In place of the paradoxes associated with the expanding universe, we are asked to accept the *tentative assumption* that newly created matter appears uniformly throughout all space. On what grounds is such an assumption tenable, and is this not the very assumption which the scientific method should seek to establish? On such an assumption we are led to the statement on page 116—" provided the creation of hydrogen atoms is *admitted* "—that is just what I personally am not prepared to admit.

The other objection to a capital theory raised on page 116, last paragraph, has little force unless the stock of hydrogen in the universe at creation is known, the date of creation assigned, and the rate of consumption specified.

No one to-day is in a position, I feel, even to say whether we are at the moment observing a representative portion of the universe, let alone criticise the hydrogen content, with so much of cosmology on the shifting sands of speculation—where the postulates are so often, it would seem, the most important bias for a biased answer. I like the thought recently expressed that it is easy in cosmology to be like the man cutting up a block of soap with a little square tool who then decides that squareness is the *sine qua non* for soapiness.

WRITTEN COMMUNICATIONS.

Mr. E. H. BETTS wrote : This paper is an authoritative review of the case for continuous creation, a theory which is itself necessitated by the theory of the expansion of the universe, which expansion is, in turn, an interpretation of the spectral shifts as velocities of recession. The whole theoretical structure resembles the proverbial castle of cards. Professor McCrea is under no illusions about this : " If it takes place as suggested . . . " ; " No definite decision can yet be reached as to the validity of the concept " ; " Further progress in theory and observation is needed in order to provide crucial tests." He acknowledges, too, that the expanding universe is an " astonishing concept," and we must remember that it is acceptance of this astonishing concept that creates the need for the perhaps still more startling concept of continuous creation.

It should be noted, further, that the rate of creation required by the theory is too minute for direct observation. This deprives the theory of all possibility of direct observational verification. The claim of Professor McCrea that the theory is nevertheless " capable of observational test just like any other " means simply that the elaborate and intricately interwoven combination of theory and observation adumbrated in his table (page 118) when carried to completion may possibly yield numerical results which " work."

Apparently we shall have to wait a long time for even these, and, in the meantime, direct observation of the present continuous creation or coming into being of new matter, whether hydrogen atoms as such or their constituent protons and electrons, is not only not forthcoming but impossible. But it is well known that many theories which may be physically false may yet provide figures which are not incompatible with experience. We must suspend judgment. In fairness to the author we would point out that such is, explicitly, his own attitude of mind. Yet, additionally, although several explanations of the spectral shifts not involving recession have come up for consideration only to be set aside, what is to prevent, after all, some much less "astonishing" explanation?

As Christians we are fascinated to observe that the theory invokes "creation." That implies a creator. But the Creator has, in Holy Scripture, revealed His creative act as taking place "in the beginning" and as being that of an ordered system, viz., "heavens and earth" (Genesis 1 : 1). This ordered system was found to be "waste and void" in *one* of its parts ("and *the earth* . . ." (Gen. 1 : 2)) and not as a whole. There is indeed revealed explicitly in Scripture no universal chaos which could correspond to a primeval and universal cloud of hydrogen or to any of the suppositional equivalents of this. Further, any action of the Creator subsequent to those days of creation is spoken of as an "upholding" and not as the creation of new matter, though it is not to be denied that this "upholding" may resolve itself into the creation of new matter. (Such, however, nowhere seems to be its meaning on careful study.)

Professor McCrea's paper reveals that science is on the move, and maybe in the right direction. It has a long journey before it. At the end it will find that Scripture has arrived first.

We thank Professor McCrea for his very honest exposition of the theory. It has been written with restraint and with very great humility, considering the author's own noteworthy contributions to the subject. The paper is in the true spirit of science.

Dr. R. E. D. Clark wrote: Professor McCrea's paper is absorbingly interesting and lucid. From the fact that he refrains from indulging in philosophical speculations, one may, presumably, draw the conclusion that he does not think that it is wise to draw conclusions until the premises have been more firmly laid.

In §6 the suggestion that fresh matter makes its appearance in space in a diffuse form certainly *seems* simpler than the alternative suggestion of the fresh creation of new galaxies—or of gas clouds about to turn into galaxies. But is not the simplicity deceptive? The condensation of a gas cloud into a galaxy is a process involving an increase in entropy. So, the further we push it back in time the more improbable, or the less "simple," is the state from which we start. A half-evolved galaxy is so difficult to treat mathematically that we are apt to imagine that an inchoate gas cloud is a simpler structure—but may not the simplicity be psychological rather than physical? From this point of view, P. Jordan's suggestion that stars are created whole seems preferable.

Professor C. A. COULSON wrote: The concept of Continuous Creation sounds at first sight extremely revolutionary. It is important, however, that we should recognise how, during the last thirty years, several separate strands in the thinking of modern physicists seem to have been leading us in this direction. One of the most surprising of these is our conviction that particles of matter can be created out of radiation. Another is our conviction that what may come out of the nucleus of an atom in a process of disintegration need not be the same as anything that was in the nucleus before. Continuous creation differs from these chiefly in that it represents the arrival of new matter out of nothing.

There are at least two important considerations which we ought to have in mind when thinking about it. The first is: is it true? the second is: what effect, if any, should it have on Christian thinking, assuming that it is true?

To the question, is it true? the scientist will answer "That depends on what you mean by truth." And for him truth requires: first fitness, second economy, and third coherence. In other words a theory is regarded as true if it appears adequate to the phenomenon it is describing, if it contributes as little in the way of new hypothesis as possible, and if it coheres with the thought forms which are current at the time. In every one of these respects the theory of continuous creation seems to satisfy our requirements.

On the other hand, this creation is not directly observable. For the creation of one atom of hydrogen in a volume the size of St. Paul's Cathedral during one year is, and probably always will be, not directly measurable. Thus, by "true" we must mean "it is *as if*. . . ." That is the only meaning that can here be given to the word "truth."

There is a little more to be said about the effect of this theory on Christian thinking. The Christian doctrine of creation was an attempt to assert that physical existence has a meaning and that meaning derives from God. Just how creation took place or whether there are other possible worlds does not matter. It may even be unknowable, or we may be able to learn it. Even the infinite age of our own Earth is irrelevant. It seems to me that there is no fundamental antagonism between this new theory and Christian tradition. One might, indeed, say that in so far as this theory provides more colour to our picture of the physical world, it helps the worship of the Christian.

It would be fair to say that Christians are now obliged to consider more seriously what they mean by the statement that the Kingdom of Heaven is not only outside space but also outside time. I believe that this incentive will be a useful one because it may help us to recognise that there are several ways in which our existence may be described, several languages which we may use ; each language is valid but each is different from the other. Questions which are posed in scientific terms such as : how old is the Universe ? can only be answered in scientific terms. That does not preclude or deny that the same question may be asked in artistic or religious terms and receive other answers. It is true that the answers given in the one language do not prescribe the answers given in another language. It is also true, however, that they affect it both by cutting out certain conceivable answers and by enlarging others. It seems to me one of the major duties of those Christians who are also scientists to explore more fully this border-line territory where echoes of at least two languages can be heard together.

Author's Reply.

I should like to express my appreciation of the stimulating remarks by Professor Dingle as Chairman and of the thoughtful comments made by him and all the other contributors to the discussion.

The treatment of the subject that I give in my paper is obviously a deliberately restricted one. It is only natural that some of the points mentioned in the discussion concern questions outside the scope of my treatment. In attempting to reply to the discussion I must, however, beg leave to keep within this scope. To do otherwise would require the writing of several fresh papers ! For instance, while I readily agree with Professor Dingle that the relation between "existence" and "observability" requires more attention, its examination would take us too far afield from the order of ideas dealt with in the paper itself. Also, while it would be entirely relevant to the subject of cosmology as a whole, it is not a new problem arising out of the possibility of continuous creation.

As Mr. Betts is kind enough to say, I have tried, within the scope of my present treatment, to present a critical account of the situation as it is at present and of the way in which further developments may be expected to clarify this situation. I feel bound to say, in response to Mr. Cousins' remarks, that matters of "dislike" and "bias," in the sense in which he uses these terms, do not have a place in such work.

A very general point is raised when Mr. Filmer refers to "the generally accepted laws which we have always considered governed the universe" and proceeds to mention the "law of conservation of matter" and "the law of conservation of energy" (and also more detailed considerations regarding kinetic energy). The point is raised by the expression "always." As a matter of history, the meanings of these "laws" have been repeatedly changed. At the time, about a century ago, when the law of conservation of energy was first formulated, the law of conservation of matter meant, presumably, the law of conservation of mass. But Einstein's special theory of relativity (1905) showed that mass and energy should be convertible into each other and this has been confirmed by observation. According to this theory, the two laws are therefore replaced by a single law. However, according to Einstein's general theory of relativity (1915), this single law cannot be stated in isolation. It has to be incorporated in a more complex law involving stress and momentum as well as mass (or energy). My recent paper (*Proc. Roy. Soc.* A. 206, 562–575, 1951) shows that the "creation" with which we are here concerned does *not* violate this general law. The remarkable thing about the concept of continuous creation is that it is a new concept which is found not necessarily to *conflict* with anything else in current physical theory.

If the process of continuous creation does occur as here contemplated and if we try to give an account of it in everyday physical language, then the sort of account given in my paper is probably the natural one. But this almost inevitably makes it appear more revolutionary than a strictly technical account would show it to be. From what I have just said, this is certainly the case from the side of relativity theory. From the side of atomic physics, no proper theory of the process has yet been given. But the considerations presented in Professor Dingle's opening remarks, the current trend of the quantum theory of "fields," and certain numerical considerations, all suggest that such a theory could result from a natural development of the subject. [This is not to say that both relativity theory and quantum theory will not be re-formulated and re-interpreted in the course of the evolution of scientific ideas. But that is another matter.]

Most contributors to the discussion ask if the red-shifts in the spectra of the external galaxies admit of any explanation other than as Doppler-displacements produced by the recession of the galaxies. Here we must be clear as to which of two possibilities is contemplated: (*a*) That the red-shift is due entirely to some unknown agency or (*b*) that the red-shift is a Doppler-displacement complicated by some other effect.

I do not think that (*a*) need be taken seriously. Not only would the unknown agency be in itself probably more difficult to admit than the possibility of continuous creation, but it would explain too much. For it would mean that the universe is in a static state and, as we have seen, this is impossible according to all existing theories of gravitation (see below also).

The possibility (*b*) would mean that the universe is expanding less rapidly than is inferred from the usual interpretation. So the difficulty regarding the "age of the universe" as compared with other ages might be resolved. Two types of suggestion have been advanced. One type does not invoke a new agency but new principles for computing the effect of a Doppler-displacement. All one can say, without going into technical details, is that these principles have not been accepted. The other type of suggestion is to invoke a new agency, as in (*a*). Here there is the same difficulty as in (*a*) about admitting the agency itself. It seems that it is not demanded by any other phenomenon in nature and it would not help towards the solution of any other problems. This should be contrasted with the possibility of continuous creation which, as I have tried to show, may lead to the solution of many other problems in cosmology. Finally, we should be admitting the necessity of two effects instead of only one in order to explain the red-shifts.

All this will, at least, show that the hypothesis of an alternative interpretation of the red-shifts is not *simpler* than that of continuous creation.

As regards the impossibility of a static universe, Mr. Cousins asks if de Sitter did not "construct a static world-model which satisfied the Einstein laws of world gravitation?" The answer is No; what de Sitter found was one particular case of the expanding universes later discovered by Friedmann and Lemaître.

It is true that, as de Sitter first worked it out, it was "static" in regard to the time-coordinate he employed. But, as is well known, his model nevertheless exhibited the phenomenon of the recession of the galaxies, *i.e.*, the "expansion of the universe." A simple transformation of coordinates (which, of course, has no effect upon the observable properties of the model) puts de Sitter's solution into the same mathematical form as a limiting case of those of Friedmann and Lemaître.

"The Einstein laws of world gravitation" used by de Sitter are those extended by the introduction of Einstein's "cosmical constant λ." Both de Sitter's universe and Einstein's static (and unstable) universe exist only if λ is non-zero. Also, Professor Dingle's statement that "capital" theories "do not necessarily require that the speed of a galaxy decreases with time" holds good only if λ has a sufficiently large positive value.

It is worth pointing out that this cosmical constant was even more mysterious than the proposed continuous creation. For it could not be interpreted in terms of any property of the local material contents of the universe. The mathematical treatment of continuous creation does not require the presence of the λ-terms in Einstein's equations, but the admission of the possibility of continuous creation achieves much the same mathematical results as those which the introduction of these terms was designed to achieve.

[For the sake of readers referring to the recent literature of the subject it is important to point out that there is a distinction between the de Sitter *universe* and de Sitter *space-time*. The latter can be, and is, used in current work which does not use the same field-relations as those which de Sitter used to derive his " universe."]

Turning to a brief mention of more detailed matters we consider, first, Professor Dingle's final remarks about the range of sizes of galaxies. As he says, on the new theory we should expect a large range of size. At any rate, to a first approximation, however, the average size would be *the same* at all distances. Also, this is all that is required for the statistical establishment of " the accepted law of the expansion of the universe," *i.e.*, Hubble's law. The empirical fact that the galaxies do possess a considerable range in size, as well as in other properties, is becoming more fully recognised (see, for instance, Professor Harlow Shapley's *Russell Lecture* for 1950).

Referring to Dr. Clark's considerations regarding entropy, we have to remember that the laws of thermodynamics as ordinarily formulated apply only to closed systems, and that temperature, entropy, etc., have precise meanings only when these systems, or their parts, are in thermodynamic equilibrium. In the present work we have to deal with a system which is neither closed nor in thermodynamic equilibrium. So I think that we cannot apply the criteria suggested by Dr. Clark.

It is true that, apart from the hypothesis of continuous creation we might devise thermodynamic considerations that could self-consistently be applied to any suitably chosen region of the universe. But, if we have to allow for the possibility of the " creation " of fresh matter in such a region, these considerations would no longer apply. It is to be noted that such " creation " would not conflict with the laws of thermodynamics : they merely become inapplicable to any problem for which the occurrence of creation is significant.

I should like to close with a general comment which I believe to be desirable. I have tried to give due recognition to the tentative character of much of the work described. At the same time, I should not wish to leave the impression that everything in modern cosmology is only tentative. Those who are working in the subject are convinced that a progressively more satisfactory theoretical system is gradually being evolved by all the processes of tentative exploration, trial and error, successive approximation, and so on, which are familiar in every branch of science. It just happens that the particular branch with which we are here concerned is, at this particular juncture, in a somewhat specially fluid state—and a specially interesting state.