COSMOLOGY*

THE universe in the large is an inevitable subject for scientific curiosity, but the most commonplace physics also leads us to study it. More generally, we conceive that the laws of physics and the actually existing physical universe must be interdependent, so that physics is bound to merge into cosmology. We may conveniently define cosmology to be the study of the astronomical universe as the system of the galaxies and any material in intergalactic space. The present time is suitable for taking stock of the subject because there seems to be a halt in its development, although much that is happening in physics and astronomy can be seen to have a bearing upon it.

The lines in the optical spectra of galaxies show a shift towards the red that increases with decreasing apparent brightness. The facts are consistent, to a good first approximation, with the interpretation that the galaxies are receding with speeds proportional to their distances. This interpretation received notable support when American observers recently found, in the few cases so far examined, that the 21 cm. line in the radio spectrum showed velocity shifts agreeing well with those in the optical spectrum. The constant of proportionality in the velocity law (Hubble's law) is written $1/\tau$; it means that if the galaxies have always had their presently observed velocities they would all have coincided in space τ years ago. The current estimate of τ, based upon W. Baade's important revision of the distance-scale, is $5{\cdot}4 \times 10^9$ years.

The fact that so general a property as the motion of the galaxies is found to be the same for all directions, strongly indicates that the universe as a whole must be isotropic about our position. The homogeneity signifies that an observer in any other galaxy would get the same general picture of the universe as we do if the universe is in a steady state, or the same sequence of pictures if it is evolving. If valid, this is the most important thing we know about the universe, for, it means that we are in a position to know all that can be known about the astronomical universe, in the sense that we could learn nothing more about its large-scale behaviour by going anywhere else within it. If the universe is in a steady state, we could further learn no more by living at another epoch, but this would not follow if the universe is evolving. It is in fact hard to see any justification for accepting the 'universality of physical law' unless there is also universality of physical background, *i.e.*, homogeneity of the universe in the large. It is satisfactory to find evidence for the latter, at any rate as regards space; whether it applies also to time is one of the main points to be discussed.

The most obvious explanation of the apparent recession of the galaxies is that we are witnessing a one-way evolution of a universe whose contents are given once and for all. The mechanical behaviour of such a system is appropriately treated by Einstein's theory of general relativity. The equations obtained have a range of solutions. Those that come nearest to fitting the observations require the material to have been in a state of enormous density, infinite in the idealized model, rather less than τ years ago. The production of this singular state is given no meaning in the theory; it must be regarded as the creation of the universe, and a unique 'age of the universe' must be dated from it.

On the other hand, the essentially simplest view is that we should suppose there to be nothing to distinguish our position in time from any other, just as we have already inferred that there is nothing to distinguish our position in space. Thus, we should suppose the universe to be in a steady state. This refers to the universe in the large or to the smoothed-out universe.

The steady-state theory of the expanding universe was propounded by H. Bondi and T. Gold and by F. Hoyle in 1948. According to the theory, existing galaxies are indeed dispersing, but, new matter is continually appearing throughout the universe and giving rise to new galaxies, thereby keeping the population distribution steady. Any large region contains galaxies of all ages, but with an average that works out at $1/3\tau$ years. The general merits of this theory are that we avoid (*a*) the dubious procedure of employing unchanging laws in a changing universe; (*b*) the paradox of finding objects such as stars that are older than the universe; (*c*) the dilemma of having everything dependent upon a creation process that nevertheless is outside the scope of the theory. However, it must be understood that discrimination between the different theories depend upon effect of second or higher order near the limits of instrumental performance.

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* Based upon an article by W. H. McCrea in *Endeavour* for January 1958.

Despite the superb work done by observers, it seems that all efforts to discriminate between the theories by means of large-scale features must still be inconclusive. This seems to apply not only to optical observations but also to radio surveys. At present therefore we must consider less direct evidence.

According to evolutionary theory, galaxies must have been formed from a space-filling gas at a definite stage in the expansion of the universe. But a satisfactory process has not so far been proposed.

The steady-state theory, however, by its very nature cannot pose the problem of an original formation of galaxies. D. W. Sciama has stressed that its problem is the self-perpetuation of the existing population with all its characteristics. He has outlined a remarkable solution of the problem which is as follows.

A galaxy is, in general, in motion through intergalactic gas by virtue of its random velocity. The gas that falls towards it as it passes, forms a wake behind the galaxy, as in the well-known theory of gravitational accretion. The wake material will tend to pull itself together by its self-gravitation and so forms a 'daughter' galaxy. There is a critical condition for the daughter to break away from her parent instead of remaining gravitationally bound. If they separate, the process will start again with each galaxy. If they remain together, the process will be repeated with the pair, and by the production of further offspring a cluster of galaxies of increasing population may result. But a cluster has an inherent tendency to lose members by 'evaporation'; this and other factors hinder its growth indefinitely. The galaxies that evaporate off maintain the distribution of random motions of the field galaxies. The characteristics of this self-perpetuating system depend ultimately upon the properties of the atomic hydrogen which constitutes the bulk of the intergalactic material postulated in the theory. The theory cannot yet be regarded as established but is attractive and has no arbitrary features.

Calculations imply that 90% of all matter is intergalactic and the mean density ρ according to original theory works out to 3×10^{-5} hydrogen atom cm.$^{-3}$ According to the steady-state theory the existing matter moves out of any region as a result of cosmical expansion and is replaced by 'new' matter once in about 2×10^9 years on the average. Thus there is a creation process which must be one involving fundamental particles and producing hydrogen. Consequently at some stage it must yield protons and electrons. Calculations reveal that over a big range of temperature there will be significant fractions of both neutral and ionized hydrogen.

The concept of continual creation has not proved repugnant to current physical theory. It has indeed provoked a further line of speculation. For, 'matter' constituted of positively charged nuclei and negative electrons, and 'anti-matter' constituted of negatively charged nuclei and positive electrons, are treated in symmetric fashion by current theory. In particular, both sorts have theoretically identical inertial and gravitational properties. On general grounds we might therefore expect any creation process to produce statistically equal amounts of matter and anti-matter and the universe in the large to be composed of equal amounts. On the other hand, any particular galaxy must be composed effectively entirely of one sort only. It has even been suggested that some very energetic collisions observed to be occurring in some parts of the universe are between galaxies of opposite compositions.

The steady-state theory has survived for nine years since its announcement. Despite its peculiar vulnerability, no observation has been found to refute it that is not itself of uncertain interpretation. The obstacle regarding nuclear synthesis has disappeared and with it one of the main arguments for the evolutionary theory. The solution of the problem of galaxy formation seems to be within reach of steady-state cosmology, while older theories have not shown much progress towards solving it

HAFFKINE INSTITUTE

THE Haffkine Institute, Bombay-12, will be celebrating its Diamond Jubilee from 10th to 14th January 1959.

The celebrations are expected to be inaugurated by the President of the Republic of India. The programmes will include lectures and scientific seminars on topics such as plague, cholera, rabies, influenza, poliomyelitis, snakes, venoms and insect resistance to insecticides. These will be on international level for participation.

All scientists, scientific organisations and learned societies are invited to attend or to send delegates so as to encourage free flow of research ideas and goodwill between Research Institutions in the world.