The Expanding Universe

THE suggestion made by de Sitter in 1917, based on the general theory of relativity, that distant celestial objects would appear to be moving away from us, and the subsequent experimental discovery that the extra-galactic nebulæ have radial velocities which are a simple linear function of their distances—these have been followed by consequences sufficiently exciting, even to a generation which has witnessed an almost complete revolution in our physical notions. The discussion arranged in Section A of the British Association at the Leicester meeting, focusing as it did a number of these later developments, roused very general interest.

Sir Arthur Eddington, who opened the discussion with a rapid review of the problem, pointed out that the observational evidence, not strong enough in itself to warrant far-reaching conclusions, is backed by relativity theory which, although it does not predict the rate, demands an expanding or contracting universe.

An application of the uncertainty principle helps to show that the theoretical rate of expansion is equal to that observed. If e is a unit vector in random direction, the uncertainty of position of a particle in space-time of radius R is Re. The mean of N particles used as a reference frame will have an uncertainty of position $(R/\sqrt{N})e$, with a corresponding momentum uncertainty of $h/2\pi.\sqrt{N}/R.e$. Taking into account the energy corresponding to this momentum vector, we find that, if a particle is referred to the reference frame provided by a random distribution of the other N particles of the universe, the proper mass of the reference frame is $m_0 = (h\sqrt{N})/2\pi cR$. This makes m_0 intermediate between the masses of the proton and the electron, if we assume the value of $\sqrt{N}/R$ given by the recession of the spiral nebulæ. In an ordinary representation proper mass is attributed to the particle instead of to the reference frame, and in a one-dimensional problem the mass m would be directly transferred to the particle. Taking account of the dimensions of the problem, the apparent mass m of a particle (proton or electron) is given by

$$10m^2 - 136mm_0 + m_0^2 = 0.$$

Prof. E. A. Milne pointed out that the observed motions of the extra-galactic nebulæ are totally different from the motions of the planets in a solar system, from double-star orbits or from star-streaming. The nebulæ are simply separating one from the other—a motion typical of particles in free flight, or possessing velocities sufficiently large to escape from the gravitational attraction of the rest. Such a system must necessarily expand and the fastest particles will, at any given epoch, be the farthest. Moreover, the velocity-distance relation is one of simple proportionality. It is suggested, therefore, that the system of the nebulæ is that of a system of particles in free flight, subject to negligible gravitational influences. The expansion is an inevitable kinematic phenomenon, and is *the most natural thing in the world*.

In discussing the general kinematics of a particle system, those systems only are selected in which all points are fully equivalent. Flat space is chosen, the choice of space being open, and it can be shown that the Lorentz formulæ are applicable; it then appears that only one system of flow is possible, a flow which reproduces the observed expansion. Moreover, the observable volume of the system is finite and the density must slowly increase outwards from any observer.

Dr. G. C. McVittie remarked that Lemaître's original theory assumed that a fair approximation to the facts might be obtained by treating the matter in the universe as if it were diffused in the form of a cosmic cloud. But in actual fact there are regions of condensation—spiral nebulæ or stars—separated by comparatively empty regions. What is the effect on the theory of an attempt to take account of this discontinuous distribution? The problem turns out to be intractable—we cannot solve even the problem of two particles. But a system in which we have one particle and the remainder of the universe a cosmic cloud may be handled, although the solution is not unique.

The Einstein universe—one in which the cosmic cloud had everywhere constant density and a very small pressure, space being spherical and closed—is unstable. The theory of Lemaître gave no indication of the direction of motion of such a universe from its equilibrium position, and the theory of condensations was first developed in order to find out whether the condensation of the cosmic cloud into particles would initiate an expansion. Unfortunately the disturbance of the equilibrium is a second order effect and the problem is mathematically so complicated that no satisfactory method of solution has yet been evolved. The theory of condensations is much more helpful in the consideration of the question of cosmic time.

Dr. W. H. McCrea dealt with the relation of Milne's theory to the general relativity theory of the expanding universe. De Sitter, on general relativity grounds, had predicted a systematic recession of distant nebulæ, for which observational support accumulated. Lemaître, Friedmann and others, using general relativity theory, arrived at the concept of an expanding universe, and an explanation of Hubble's empirical law for the variation of recession-velocity with distance. Milne then suggested an explanation of the recession which might stir someone to the remark that, had it been propounded earlier, it might have saved us all the trouble of trying to fathom general relativity. But general relativity is really the best mathematical method for dealing with Milne's phenomenon. Consider the simplest solution of Milne's problem. He chooses his space-time first and then seeks that gravitational law which will reproduce the actual state of affairs. General relativity, on the other hand, puts the gravitational law first and then seeks a form of space-time which will reproduce the actual system. The general relativity theory of the expanding universe admits a whole class of curved spaces. Choose the right one with λ equal to zero, neglect the gravitational interaction of the particles and we obtain Milne's universe as just considered. We then proceed to discuss the effect on Milne's theory of an allowance for the detailed gravitational attraction of the particles.

M. l'Abbé Lemaître remarked that the theory of the expanding universe demands a modest age for the universe—a period a thousand times less than that dependent on the usual theory of the evolution of the stars. Can the expanding universe theory substitute for this slow evolution a more rapid process ? It *is* possible to envisage a process in which the universe in general starting with a small radius expands with a diminishing velocity, until the equilibrium radius is reached, when it will expand with an accelerated velocity. Interior regions of a somewhat greater density might fail to attain equilibrium and contract, while the universe at large continues to expand. Hence the rapid formation of nebulæ. A difficulty arises, inasmuch as for a condensation of the thousand millions suns required for a normal nebula the equilibrium radius is about 80,000 light years, instead of the 1,000 light years radius of a typically elliptical nebula. Consideration of the energy turned into heat by the rapid concentration of diffuse matter into stars minimises this difficulty, and we may picture stars and nebulæ as being born together in an astronomical instant, a sudden evolution of the universe taking the place of a slow evolution of the stars.

Prof. de Sitter's masterly survey of the problem almost defies analysis. He discussed three of the theories proposed for the explanation of the linear velocity-distance formula found for the recession of the spiral nebulæ. He remarked of Milne's theory that the frequency law of the velocities V of the spirals is rather artificial. But the principal objection to the theory is that it ignores the fact that on the relativity theory of gravitation, it is impossible for the velocities V to remain constant.

'Solution B' of the general field equations of the relativity theory shows that the locus of a spiral is a hyperbola described with a variable velocity, the radial component of which, at large distances from the origin, is given by $V/c = \pm hr$. A special hypothesis, that the spirals are all on the receding branches of their hyperbolas, is required to give the velocities a positive sign. But the theory had to be abandoned because it requires an 'empty universe', that is, a universe containing a density of matter so low as to be indistinguishable from zero.

The solutions on which the third theory is based are due to Friedmann and to Lemaître. In Lemaître's theory the formula $V/c = hr$ is rigorous, and it provides the required adjustment between the observed coefficient h and the observed density.

The shortness of the time that has elapsed since the 'beginning of the universe'—that is, since the time of minimum mutual distances of the galaxies, as compared with the accepted ages of the stars, has been expressed by the statement that 'the stars must be older than the universe'. This sounds paradoxical, but there is really no paradox. The ages of the giant Redwood trees in California are of the order of 2,000 years but California, as a State, is less than a century old. We do not for this reason revise our estimate of the ages of the trees, but we conclude that trees could live in California before California was born. Similarly stars could exist in the universe before it attained its present configuration.

One of the most important of the services which the British Association renders to the public is that of organising discussions which may assist in elucidating the more difficult scientific problems of the day. The expanding universe discussion was, perhaps, rather on the technical side, but it was memorable alike for the subject and for the personalities engaged therein, and it will rank high on the list of those great discussions with which the name of the Association is linked. A. F.

Recent Developments in Television*

By Archibald Church, D.S.O., M.C.

All development of the art of television is recent. It is less than ten years since John Baird first obtained televised images of simple stationary objects such as a Maltese cross. He first demonstrated 'real' television, the instantaneous reception of optical images of moving subjects, images of which had been transmitted by means of a variable electric current, on January 27, 1926. Most of the scientific workers and publicists present at that demonstration, while impressed by the achievement, were frankly sceptical of television ever achieving any position as a medium of entertainment or of its being put to other commercial uses. The received images were recognisable, but blurred and flickering, and to many scientific workers, a proof of the impossibility of advance in television by a mechanical system of transmission and reception. Other scientific observers, though less antipathetic to the mechanical system, were unconvinced that television broadcasting would ever be practicable owing to the wide range of frequencies which

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* Paper read before Section A (Mathematical and Physical Sciences) of the British Association at Leicester on September 13.