If the solar system was generated by nine or more photon absorptions, most of the stars in our neighbourhood must have absorbed several photons, and produced planets. If it only absorbed one, the frequency of long-period binaries suggests that events of this type were not rare, so that our galaxy may include some hundreds of millions of planetary systems. If so, the field of biology is probably wider than has been suggested.

The galaxies have masses of the order of 10^{45} gm. This is the mass of a photon of period 10^{-92} sec., that is, of the minimum photon at $t = 10^{-92}$ sec. Even if the galaxies were originally particles of matter as closely packed as atomic nuclei, and therefore of rather less than the size of the sun, the energies needed to disrupt them into gas were considerably less than that of such a photon. Hence if the galaxies originated by the absorption of radiation, in which case some of Milne's 'fundamental particles' may still exist in a compact form, or even if their whole mass arose from radiation, they cannot date from before $t = 10^{-92}$ sec., or $\tau = -5 \times 10^{11}$ years. Thus the long time-scale of about 10^{12} years deduced from a study of gravitational interactions of stars, which are naturally measured in dynamical time, appears as a consequence of Milne's theory.

The above arguments must be regarded as the attempt of a layman to deduce some of the consequences implicit in Milne's cosmology, consequences which he had partly envisaged when he wrote in 1936 that "all dynamical theories of the origin of the solar system may require drastic revision". I have doubtless missed other consequences as important as any which I may have elicited. Even if my hypothesis is found to be logically coherent, it may well prove, when fully developed, to be as untenable as Laplace's nebular theory. In particular, the secular stability of non-radiating ionized gaseous spheres and the relation of the uncertainty principle to the scale of time will require investigation. Above all, the details of the postulated process were in principle unobservable, and it will therefore be hard to test the proposed theory as rigorously as others have been tested in the past. This is a serious defect, since the value of a scientific theory increases with the number of ways in which it can be tested. But much of current physical theory has the same defect.

I have not suggested an origin for the postulated photon or photons. To do so would involve either a further step in a possibly infinite regress or the assumption that they were primordial constituents of the universe. They might, for example, have been generated by the acceleration of large charges during the origin of the galaxies. It may be asked what is their present state, if any of them have not been wholly or mainly converted into kinetic energy. The energy of a photon is invariant on the kinematic scale appropriate to the particle emitting it; but since a particle absorbing it is moving away from its source, its frequency and energy are lowered by the Doppler effect, and on the kinematical scale appropriate to such a particle, both vary as t^{-1}, where t is the epoch of absorption. Thus the postulated planet-making photons are now trains of electromagnetic waves of a period of the order of a year, and much too small to be observable in practice. The mass of matter at any time is thus the fraction of the mass at an earlier time which has not been degraded by the Doppler effect, and at a sufficiently early date most of the mass of the universe, or all of it, may have been radiation rather than matter.

In conclusion, I wish to thank Prof. Milne for his encouragement, and for elucidating several details of his cosmology in letters; and to emphasize that if the theory here sketched has any value at all, it will only prove its value by serving as a basis for exact calculations by persons better versed than myself in physics and astronomy.

[1] "Problems of Cosmogony and Stellar Dynamics" (Cambridge, 1919). "Astronomy and Cosmogony" (Cambridge, 1928).

[2] "Relativity, Gravitation, and World Structure" (Oxford, 1935). *Proc. Roy. Soc.*, A, **154**, 22 (1936); **156**, 62 (1936); **158**, 324 (1937); **159**, 171, 526 (1937); **160**, 1, 24 (1937); **165**, 313, 333 (1937). *Phil. Mag.*, **34**, 73 (1943).

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Prof. Haldane's idea as developed in the foregoing article seems to me to be fundamentally important. As all may not be familiar with the details of kinematic cosmology, and as readers may have difficulty in keeping pace with the rapier-like speed of Prof. Haldane's mind, I beg to be allowed to traverse some of the same ground in more pedestrian fashion.

To begin with, a word of explanation: I first announced my ideas on the two time-scales at the Blackpool meeting of the British Association, in a discussion on the origin of the solar system; but the consequences of the ideas were so bizarre that I felt it to be absolutely necessary to develop the formal and philosophical aspects of the theory in full detail before proceeding to the more speculative consequences. This programme I carried out in a series of papers published by the Royal Society during 1936–38, and, though hindered by war-work, in *Philosophy* (1941), in addresses before the London Mathematical Society (1939), the Royal Society of Edinburgh (1943), the Royal Astronomical Society (1944) and in a series of papers in the *Phil. Mag.* (1943). I am at present wrestling with the difficult problem of the conservation of linear momentum for gravitating bodies in the expanding universe, and I do not wish to be hustled. However, in *Proc. Roy. Soc.*, A, **165**, 354 (1938), discussing the role of the correspondence principle on the two time-scales, I wrote: "It is not a fanciful speculation to see in the interplay of radiation keeping t-time with matter obeying the classical laws of mechanics on the τ-scale a phenomenon giving rise to the possibility of change in the universe *in time*, and so an origin for the action of evolution in both the inorganic and organic universes". A possible mode of that interplay has now been pointed out by Haldane.

I have long been aware that all theories of the origin of the solar system require drastic re-consideration in the light of the fact that at times of the order of $t = 0$, when the solar system was born, dynamical and optical conditions were very different. Haldane works with equal facility in either time-scale; but it must be remembered that the τ-scale is a concession to our Newtonian predilections, that it has in its description a constant t_0 (the present age of the system on the t-scale) which has nothing to do with *phenomena*; it has to do only with the language by which we describe the phenomena. Phenomena themselves are best studied through the t-scale, and in this scale the precise value of t at the epoch studied is all-important.

In Haldane's calculation of the order of magnitude of the energy required to be communicated to the sun to form the solar system of planets, he uses the formula $\gamma mM/R$, with the present values of γ and R. It might be objected that on my theory $\gamma \propto t$, and that therefore the required energy was then much smaller. The answer is that $R \propto t$ also, that energy is a 'time-invariant', and that Haldane's calculation is accordingly correct. On his data, the value of $\gamma mM/R$ is 5×10^{45} ergs, as he says.

Previous speculators on the early history of the universe had always argued that since the universe is expanding, collisions must have been then more frequent, forgetting that lengths of material objects (that is, radii) would have then been much smaller. By translating to the τ-scale (stationary universe) we see that collisions would be just as frequent, or as infrequent, as now. The new contribution which Haldane makes is that the optical situation would be entirely different. At epoch t, when the radius of the expanding universe was ct, there cannot well have been photons of wave-length exceeding ct. The inequality $l < ct$ implies for the frequency n the relation $n = c/l > 1/t$. (Here l and n are measured on the t-scale.) Working again on the t-scale, the inequality $\Delta E = h_0 n > h_0/t$ gives the minimum permissible photon energy. Taking $h_0 = 6{\cdot}55 \times 10^{-27}$, at epoch $t = 10^{-72}$ sec., we get $\Delta E > 6{\cdot}5 \times 10^{45}$ ergs, so that such photons as were then possible would have sufficient energy to disrupt the sun and form a solar system.

There is no difficulty as to where the photons could come from. For according to kinematic relativity the mass (actual) and energy of the universe are infinite ; and light must be present. Hence it must be, at small t, of enormous frequency and energy. The state of material atoms would be one of complete ionization ; and the history of any photon would be one of successive degradations of frequency by interaction with matter, until at the present epoch light is *mostly* as we know it. This degradation of the individual photons due to interacting with matter must be distinguished from their constancy of frequency in time (t-scale) as they are propagated through empty space.

The epoch at which a photon ΔE was not less than $6{\cdot}5 \times 10^{45}$ ergs was, on the t-scale, 10^{-72} sec. The τ-measure of this epoch was $\tau = t_0 \log(t/t_0) + t_0$. The 'time ago' at which it occurred is $\tau_0 - t$, where τ_0, the present epoch on the τ-scale, is equal to t_0. This gives

$$\begin{aligned}\tau_0 - \tau &= t_0 - \tau = t_0 \log_e(t_0/t)\\ &= 6{\cdot}3 \times 10^{16} \times 2{\cdot}3 \times \log_{10}(6{\cdot}3 \times 10^{16}/10^{-72}) \text{ sec.}\\ &= 6{\cdot}3 \times 10^{16} \times 2{\cdot}3 \times 88{\cdot}8 \text{ sec.} = 4{\cdot}1 \times 10^{11} \text{ yr.},\end{aligned}$$

in agreement with Haldane. This is of the order of the 'long' time-scale estimated by gravitational methods, that is, on the τ-scale.

Haldane's fundamental idea (pressing it to its limit) may be stated in the form that, just as the epoch $t = 0$ is a singularity in the mechanical t-history of the universe—an epoch at which the density was infinite—so the epoch $t = 0$ is a singularity in the optical history of the universe, namely, an epoch at which the frequency of radiation was infinite, because the wave-length had to be zero. Actually we can only make significant statements about the radiation for *small* epochs t, when the frequency would on the whole be very large. A spectrum would soon come into existence, by the absorption and backward emission (or backward scattering) of radiation by the naturally receding particles, with resulting degradation of frequencies by the cumulative Doppler effects. But some of the original high-frequency radiation would traverse space unscathed, and, in spite of the inevitable Doppler effect at the terrestrial receiving end, a small fraction of this would retain a still very high frequency, and might be the origin of the undulatory component of the present cosmic rays.

I think it would be wise, in this preliminary discussion of Haldane's idea, not to go into details as to how a primordial photon of huge energy could disrupt a star. It is sufficient to dwell on the remarkable result that Haldane has deduced from kinematic relativity, namely, that at very early epochs in the history of the universe, such photons as there were must have possessed enormous energies.

WIREWORMS AND FOOD PRODUCTION

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WIREWORMS are undoubtedly the most notorious of all insects of agricultural importance, probably because their depredations are more extensive at times of agricultural expansion and prosperity. The traditional agriculture of Britain has been mainly the type known as 'mixed farming', and the measure of prosperity has been the extent of land under the plough. Wireworms are grassland insects, and so long as grassland is undisturbed they are of no economic importance. Periods of agricultural depression are periods of increasing areas of grassland, both cultivated and derelict, and consequently periods in which the numbers of grassland insects increase. Events that lead to high prices for cereals—the Napoleonic wars and the Corn Laws in the first half of the nineteenth century, and the German wars in the twentieth century—are associated with the ploughing up of grassland, and the enhanced value of the crops stimulates the interest of the farmer in the causes of crop failure. It is a simple proceeding to pull up dying plants, and only too frequently the expected wireworms are found at their roots.

In reports of the Board of Agriculture during the War of 1914–18 it was noted that in specified districts wireworms were responsible for the "complete destruction of cereal crops". Although it is doubtful whether wireworms caused all the loss imputed to them, the prospect of another European war and the consequent need for a great increase in cereal growing in Britain made imperative some reconsideration of the wireworm problem. The difficulties confronting the agricultural advisory entomologists were considerable. During the post-war years there had been little investigational work on wireworms, and their occurrence as a field pest had only been occasional in a period when cereal production was declining and little established grassland was being broken for arable culture. Farmers required advice and assistance long before the five-year period necessary for the observation of the wireworm life-cycle could be completed and while only the scantiest of information was available on the distribution of wireworms in the soil and the density of wireworm populations. The scale of the national ploughing policy and the speed with which it had to be carried out precluded the development of direct control measures aiming at wireworm destruction and compelled resort to modifi-