LETTERS TO THE EDITORS

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The Ageing of Light

RED-SHIFTS in the spectra of the galaxies are usually interpreted as Doppler effects consequent on recession. Alternatively, they have been interpreted as an 'ageing' of light with time, by which the wave-length of a photon steadily increases. That the two interpretations are substantially equivalent can be seen from the following strikingly simple calculation. I adopt the kinematic model of the expanding universe.

Suppose a photon has left our own galaxy at epoch t_1, when its frequency was ν_1, and has adventured into intergalactic space. In due course it may encounter one of the receding galaxies and be scattered or reflected. I consider only the case of direct reflexion back to ourselves. Let this photon be reflected after traversing a fraction f of the radius of the universe measured at the instant of reflexion; that is, let it be reflected at epoch t_2 when the radius of the universe is ct_2 and the distance of the reflecting galaxy fct_2. Then, since the speed of the photon is c, we have

$$t_2 = t_1 + fct_2/c = t_1 + ft_2,$$

or

$$t_2 = t_1/(1-f);$$

and the photon arrives back at our own galaxy at epoch t_3, where

$$t_3 = t_2 + ft_2 = t_1\frac{1+f}{1-f}.$$

It is then either reflected outwards again or propagated through our galaxy unimpeded. In either case it suffers no change of frequency at our own galaxy, but moves out again into intergalactic space, there to be eventually reflected back to us, and so on. After n such external reflexions back to us, it reaches us at epoch t_{2n+1}, given by

$$t_{2n+1} = t_1\left(\frac{1+f}{1-f}\right)^n;$$

for, as is easily shown, the fraction f measuring the mean free path will be the same at all epochs.

At the first external reflexion, the frequency ν_1 is reduced by the *square* of the usual Doppler factor

$$\left(\frac{1-v/c}{1+v/c}\right)^{1/2},$$

once because of its absorption by the receding galaxy and once because of its re-emission by the same galaxy. Here v, the recession velocity, is by the velocity distance law $fct_2/t_2 = fc$. Hence the frequency is reduced to

$$\nu_1\left(\frac{1-f}{1+f}\right).$$

After n such external reflexions, its frequency is reduced to

$$\nu_1\left(\frac{1-f}{1+f}\right)^n.$$

If now we call ν_0 its present frequency, t_0 our present epoch, we can write these results in the form

$$\nu_0 = \nu_1\left(\frac{1-f}{1+f}\right)^n,\ t_0 = t_1\left(\frac{1+f}{1-f}\right)^n.$$

Hence $\nu_0/\nu_1 = t_1/t_0$ or $\lambda_0/\lambda_1 = t_0/t_1$.

Thus the wave-length of the photon is proportional to the epoch at which it is observed, independent of the value of its mean free path.

If we now pursue the history of the photon *backwards* in time, we see that as $t_1 \to 0$, $\nu_1 \to \infty$. Thus at the epoch of 'creation', $t = 0$, there is a singularity in photon-frequency. This is an inevitable converse of the phenomenon of the ageing of light with time. The result is in accordance with the views, put forward on other grounds, recently reached by Prof. J. B. S. Haldane[1].

This result is compatible with the reception by ourselves of *all* frequencies at the present epoch, including the very high frequencies of the undulatory components of cosmic rays. It is thus possible that high-frequency cosmic rays are relics of the primitive high-frequency radiation.

E. A. MILNE.

Wadham College,
Oxford. Feb. 6.

[1] *Nature*, **155**, 133 (1945).

Dynamic X-Ray Reflexions in Diamond

As was first shown by Raman and Nilakantan[1,2,3], the (111) crystal planes in diamond exhibit sharply defined reflexions of monochromatic X-rays incident on them which are distinct from the well-known Laue and Bragg effects. The same authors[3] showed that the positions of these reflexions are in perfect accord with the Raman-Nath formula derived on the basis that they arise from the quantum mechanically excited infra-red vibrations of the crystal lattice.

It has been claimed by Dr. Kathleen Lonsdale[4] that the reflexions the positions of which are given by the Raman-Nath formula are not exhibited by the kind of diamonds which are transparent to the ultra-violet up to 2250 A. To check this claim we have carried out a series of studies with a number of cleavage plates of diamond of this variety, with the result that Mrs. Lonsdale's findings are *not* confirmed. Our experiments were made with half a dozen different specimens, and we find no difficulty in recording the reflexions sought for with every one of them by giving adequate exposures. The real test whether the recorded effects are those being looked for is the dependence of their intensity on temperature. A thorough examination of this was carried out with one of our specimens (N.C. 125) over a wide range of temperatures, namely, from liquid air temperature upwards to 600° C., and over a variety of settings of the crystal. Microphotometric investigations showed no noticeable change of intensity as between 30° C. and − 187° C., while there is approximately a 5 per cent increase in going up to 300° C., and about 15 per cent in going up to 600° C. These changes are in accord with the theoretical formula given by Sir C. V. Raman, if we assume that the frequency change involved in the dynamic reflexion is that of the fundamental vibration of the lattice, 1332 cm.$^{-1}$ in spectroscopic units. These results are illustrated by the accompanying photographs.

The appearance of sharply defined and intense X-ray reflexions of the dynamic kind can only be expected if the vibrations of the lattice have coherent phase relationship over a great many crystal spacings, and this in its turn evidently requires a high degree of crystal perfection. The investigations on diamond by Sir C. V. Raman and others at Bangalore have