LETTERS TO THE EDITORS

The Editors do not hold themselves responsible for opinions expressed by their correspondents. No notice is taken of anonymous communications

Blue Sun and Moon

Although the blue sun and moon are noteworthy phenomena, the physical origin of the colour does not appear to be well known. While, therefore, the following explanation is presumably neither novel nor complete, it may interest those who wish for "the vivid colouring of a physical illustration".

The cause of the sun appearing red has long been known to be due to the preferential scattering of blue light relative to red by dust particles and to small-scale fluctuations in refractive index in the atmosphere. Rayleigh showed that for particles of any given size much smaller than the wave-length, the scattering of radiation is inversely proportional to the fourth power of the wave-length; thus, for particles of less than 0·1 micron in diameter, light of wave-length 4000 A. would be scattered nine times more effectively than light of wave-length 7000 A. For the sun to appear blue, the relative magnitudes of scattering must be opposite to those which the Rayleigh theory predicts. This opposite condition can arise when the particles do not obey Rayleigh's criterion of being small compared with the wave-length.

The theory of scattering of electromagnetic radiation by spherical particles above the Rayleigh limit was first worked out by Mie[1], and extensive computations have since been made, by several workers, of the scattering under different conditions. Fig. 1 shows, for example, a curve derived by a method due to van de Hulst[2] of the variation with wave-length of the 'extinction' produced by a dielectric sphere. 'Extinction' is defined as the ratio of the effective cross-section over which radiation is stopped or diverted by a body to the geometrical cross-section which the body presents to the incident radiation.

A qualitative explanation of the main features of the curve can be given without going into detailed theory, and for this purpose the curve may be divided into three regions. The first (*A*) is the Rayleigh region, where the particle radius r is small compared with the wave-length λ, and the curve from the origin obeys the fourth-power law. The third region (*C*) is where the sphere is much larger than the wave-length; here it can be shown that not only does the sphere divert by refraction or reflexion all the radiation that falls upon it, but that it also diverts an equal amount by diffraction in the region around its edges. This fact, of which Walton[3], for example, gives a simple explanation, produces an extinction value of 2 instead of 1; this value is constant for all wave-lengths small compared with the sphere.

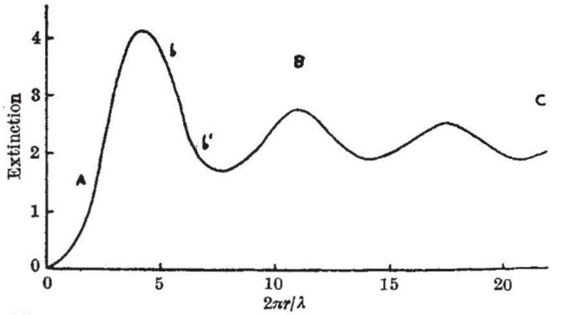

Fig. 1. Theoretical extinction of radiation of wave-length λ produced by a dielectric sphere of radius r, and refractive index 1·5

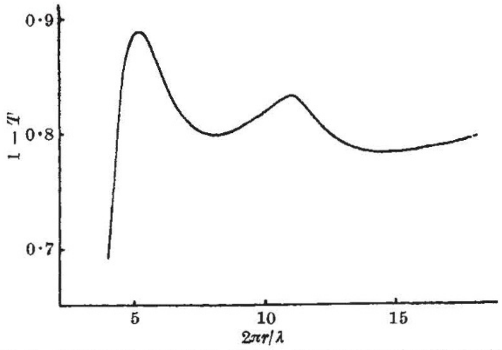

Fig. 2. Observed variation of (1 − transmission) with $2\pi r/\lambda$ for glass spheres of radius 3·5 microns and refractive index 1·5

In the intermediate region *B*, the Mie theory shows several peaks. These again could be expected qualitatively, since the particle size is here comparable with the wave-length, and resonances might occur, the fundamental being presumably the strongest. It is well known that in resonance the resonator effectively absorbs and re-emits radiation from a cross-section which may be several times its geometrical cross-section, and since the re-emission occurs in all directions, nearly all this radiation is effectively diverted from its original direction. The effective cross-section might therefore be expected to reach maxima at a series of values corresponding to the resonances, giving the form of curve predicted by the Mie theory. This form of curve is confirmed by observations on the scattering of infra-red radiation by small glass spheres[4]. Fig. 2 shows a typical observed curve for glass spheres of diameter 7 microns. The transmission of a screen consisting of a monolayer of many separate particles was actually observed; and (1 − transmission), which should be directly proportional to the extinction produced by a single particle, was plotted against $2\pi r/\lambda$.

The form of the intermediate region in Fig. 1 will account for the blue sun. Wherever the extinction curve is rising, light of longer wave-length will be scattered less than that of shorter wave-length, as in Rayleigh scattering; but wherever the extinction curve is falling, the opposite will be true. In order, therefore, for red light from the sun to be scattered more than blue light, the atmosphere must contain a large number of particles of greater size than usual, and those particles must be grouped in a narrow size-range, corresponding to such a region as *bb'*. A typical diameter would be 1·7 microns for particles of refractive index 1·3, and 1 micron for refractive index 1·5. Such conditions occur only rarely and require either a large-scale liberation of uniform particles of suitable size into the atmosphere, or (more probably) the separation by some atmospheric process of particles in the suitable size-range from a cloud of particles of random size. A corollary to the blue sun is that the sky might at the same time appear pink instead of blue.

William Paul
R. V. Jones

Department of Natural Philosophy,
University of Aberdeen. July 30. [See also p. 545.]

---

[1] Mie, G., *Ann. Phys.*, **4**, 25, 377 (1908).

[2] Van de Hulst, H. C., "Recherches Astr. de l'Observ. d'Utrecht", **11**, Pts. 1 and 2 (1946).

[3] Walton, W. H., Inst. of Chem. Eng. and Soc. Chem. Indust. Symposium on Particle Size Analysis, 141 (1947).

[4] Paul, W., and Jones, R. V., *Research*, **3**, 98 (1950).