New Facts of Colour Vision.

By DR. F. W. EDRIDGE-GREEN.

THE White Equation.—The fact that when two or three simple spectral colours are combined a white is produced which matches that from which the spectrum has been formed is the basis of many theories of colour vision. It is therefore of fundamental importance to any theory of colour vision.

In a recent paper (Proceedings of the Royal Society, B, vol. xcii., 1921, p. 232) it was pointed out that when an exact match of a red of λ 6670–6770 Å., a green of λ 5144–5156 Å., and a violet of λ 4250–4267 Å. with white was made, after fatigue with red light in the region of λ 670μμ, there was no longer a match between the simple and mixed whites, the mixed white appearing bright green, and in order that a match could be made the green had to be reduced to about one-half of the amount required by an unfatigued eye. It is obvious, therefore, that the underlying physiological processes are not the same with the mixed and simple whites. It should be noted, however, that no change in the equation is seen when the eye is fatigued with red light in the region of λ 780μμ.

Another fact of colour fatigue bears on this point; red of λ 670μμ can be matched with red of the end of the spectrum by varying the intensity, and so it has been stated that red λ 670μμ, as well as the terminal red, affects only the hypothetical red sensation. If, however, the eye be fatigued with red of the region of λ 760μμ, and red of the region λ 670μμ be afterwards viewed, this appears yellow, or even greenish-yellow, which could not be the case if the red sensation only had been affected.

The Change of Hue produced by the Addition of White Light to Spectral Colours.—White light is a purely relative term. The white light of the sun is not the same as that from an artificial source; the term is therefore employed as meaning the combined light of the source which is used. In making the experiments described, the light was that of a 1000-candle-power tantalum arc, which, compared with sunlight, is yellow. The apparatus used in these experiments was that described in the Proceedings of the Royal Society, B, vol. xcii., 1921, p. 232.

Various spectral colours were isolated on a screen coated with magnesium oxide, and definite proportions of white light taken from the source added. The scale of white light is arbitrary, the maximum amount of light it is possible to add being 100 divisions. A comparison white light taken from the source was used. Each colour became less saturated on adding white light. Red first became orange, then yellow. Orange became yellower. λ 585μμ, pure yellow, did not change in hue. Orange-yellow and yellow-green became yellow. Green became yellow-green. Blue, λ 480μμ, became white, the comparison white appearing yellow. The violet end of the spectrum from λ 480μμ, making a blue on the screen, changed to violet on adding 33 divisions of white light; light purple, on adding 100 divisions. Wave-length 585μμ, the point where the addition of white light produces no change of hue, is also the centre point of pure yellow and the apex of the luminosity curve.

The result of these experiments shows that the component part of white light which has the greatest luminosity effect is the hue to which all colours tend on the addition of white light.

The Anomalous White Equation without Colour-blindness.—Just as a man may make an anomalous Rayleigh equation without any evidence of colour-blindness (Proceedings of the Royal Society, B, vol. lxxxvi., 1913, p. 164), so may a man make an anomalous white equation without being colour-blind. As an example of this, a man was examined who presented no sign of colour weakness. He passed my card test, lantern test, and spectrometer with the ease and accuracy of an absolutely normal-sighted person. His luminosity curve was taken by the flicker method and corresponded with the normal. The wave-length of the apex of the luminosity curve was at 585μμ, which is the normal point. When, however, his white equation was taken, he put only eight scale-divisions of green instead of thirteen and a half or fourteen, which is normal, and the mixed light appeared red to the normal-sighted. An important fact was noted, namely, that after fatigue with red in the region of λ 670μμ the equation changed to him in the same way as the normal-sighted, and he required only four scale-divisions of green instead of eight. It is quite obvious that this was not a case of partial red-blindness.

The White Equation and Colour-blindness.—The colour-blind have been classified by some as red- or green-blind, in accordance with their white equations, those who put too much red in the equation being classed as red-blind and those who put too much green in the equation being classed as green-blind. There are, however, many who, whilst agreeing with the normal equation, are quite satisfied when a considerable additional amount of green or red is added to the equation. This explains why in certain cases some have been described as red-blind by one observer and green-blind by another.

A remarkable fact which does not seem to have been previously observed is that many colour-blind persons who strongly object to the normal match, but are satisfied with an anomalous equation, will completely agree with the normal equation when the comparison white light is increased in intensity so that it is much too bright to a normal-sighted person. This clearly shows that the normal mixed white produces the same effect so far as colour is concerned, but has a more powerful effect as to luminosity. This is in complete accordance with other observations, and is found in those cases in which there is abrupt and slight shortening of the red end of the spectrum. If there be shortening of the red end of the spectrum which does not affect λ 670μμ, and λ 670μμ has its normal light value, the mixed light will be more luminous than the simple white in the exact proportion of the shortening. This portion of red light not producing any effect has to be subtracted from the white light.

These facts are quite inconsistent with a hypothetical red sensation which is affected by light of all wave-lengths. Another illustration may make this point clear. A man with shortening of the red end of the spectrum and normal colour discrimination will put together as exactly alike a pink and a blue or violet much darker. If, however, the pink and blue be viewed by a normal-sighted person through a blue-green glass which cuts off the red end of the spectrum, both will appear identical in hue and colour. This proves conclusively that the defect is not due to a diminution of a hypothetical red sensation, because all the rays coming through the blue-green glass are supposed to affect the red sensation, and yet we have been able to correct the erroneous match by the subtraction of red light. On the other hand, there are colour-blind persons who, whilst dis-

agreeing with the normal white equation, agree with it when the comparison white is diminished in intensity.

The facts in this article, whilst in complete accord with those previously given ("The Physiology of Vision," G. Bell and Sons, 1920), are inconsistent with any theory of three fundamental sensations of which the other colour sensations are compounded.

Defects of light perception are quite distinct from defective colour discrimination. All degrees of colour discrimination may be classified as dichromic, trichromic, tetrachromic, pentachromic, hexachromic, and heptachromic. This classification is fact and not theory. For instance, the dichromic have two colour sensations, red and violet, with a neutral division in the spectrum. There are innumerable varieties of dichromic vision, as there may be shortening of either end of the spectrum or defects in the luminosity curve. When the luminosity curve is the same as the normal there is no evidence to show that the perception of white is not the same as the normal.

I must express my indebtedness to Capt. Fulton and Mr. Isaacs, of the Board of Trade, for their help in making these observations.

Regional Geology.

OUR knowledge of the geology of England is enriched by Dr. J. E. Marr's conception (*The Naturalist*, February, 1921) of Yorkshire as an earth-block surrounded by down-folded strata, but with its own Carboniferous series little disturbed, owing to the rigidity of a pre-Cambrian mass beneath. The block, which became tilted somewhat to the east, has had an important effect on the drainage, and even on the progress of ice-sheets, in northern England.

A useful summary and map of the geology of Jersey, by G. H. Plymen, appear in the Proceedings of the Geologists' Association, vol. xxxii., p. 151 (1921), a journal that has maintained its characteristic features despite the difficult conditions following on the war. The Geological Survey should find a ready sale, even at the price of 10*s.*, for its "Short Account of the Geology of the Isle of Wight," by H. J. Osborne White (1921), which contains a coloured geological map on the scale of one quarter of an inch to one mile. The second edition of the memoir that it succeeds is now exhausted, and we must look back on that handsome cloth-bound volume, issued at 8*s.* 6*d.*, with the customary regret. But Mr. White's treatise is not a mere abridgment of the older one, since he brings to the work his wide knowledge of the south-east of England, and of the literature of the intervening thirty years. He adds original drawings, showing the development of the surface and the relations of the rocks to well known scenic features, and geologists who are fortunate enough to possess the memoir by Reid and Strahan must now add its successor to their libraries before they start once more for the island. Here, again, the question is raised as to whether memoirs by public surveys should be supposed to cover their own "cost of production," or whether their dissemination should, as in Canada and the United States, be regarded as a part of public education.

Dr. Arthur Winkler, as Ordnance-officer of the 7th Gebirgsbrigadecommando, was stationed at Santa Lucia, near Tolmino, in 1916, and found time to extend F. Kossmat's researches on the central Isonzo valley. He remarks, in the true spirit of science, that the war had inflicted wounds on the mountain-sides, and that many new exposures required registration. His observations, continued in 1918, are now recorded in a paper in the *Jahrbuch der geologischen Staatsanstalt*, vol. lxx., pp. 11–124 (1920), illustrated by numerous sections showing the Alpine folding of the strata, from the Triassic limestones to flysch of Eocene age. Glacial beds, dumped down into the valley, play an important part in the dusty groove, and walls of pebbly calcicrete are undermined by the green swirls of the Isonzo. Above them tower the crags of contorted limestone, marked by brown scars where slabs of rock have fallen away. Dr. Winkler's work brings back happier memories than those recently associated with the Bainsizza Plateau and Caporetto.

The Geological Survey of India issues a handsomely illustrated memoir, by C. S. Middlemiss, on Idar State, which lies on the tropic in the north-east of the Bombay Presidency. Evidences of solar weathering are given in the fine views of granite surfaces. The main interest of the district lies in the junction of the Delhi quartzite with the underlying series of Aravalli schists and gneisses. Quartzite blocks again and again appear to be stoped off into the Aravalli rocks; but the latter cannot in all cases be regarded as igneous invaders. The author suggests that the igneous masses which penetrate the Aravalli series softened the metamorphosed sediments until they behaved as a semi-solid or plastic mass. The floor of Finland seems to offer much support to his conclusions.

Dr. W. F. Hume, untiring in his surveys of barren lands, has issued, with his colleagues, a preliminary report on Abu Durba (Western Sinai). This bulletin, dated 1921, is No. 1 of a series on petroleum research. The oil that is traceable at Abu Durba seems to have been absorbed from shales into the Nubian sandstone, and may originate (p. 11) in organic matter washed down with the shale-particles into the Cretaceous sea.

A. L. Du Toit (Union of S. Africa, Geol. Surv., Explanation of Cape Sheet 28, 1920) traces in Pondoland the great monoclinal flexure that, as Penck showed, is responsible for the edge of the plateau-lands of south-eastern Africa. The down-folding has determined the coast-line, and ceased about the close of Cretaceous times. The inland region, however, continued to rise, since Upper Cretaceous beds, near East London, occur 1100 ft. above the sea. The shelves over which the rivers reach the sea represent successive stages of the uplift. One is inclined to ask once more: When was the great peneplain of the plateau-surface formed? How has it escaped dissection inward from its Eocene edge? Has it been perpetuated by wind-action in a region where rains are only seasonal and droughts are more prevalent than rains?

The first pamphlet of the Geological Department of Uganda (Entebbe, 1920) is written by E. J. Wayland, and is intended to direct the attention of residents to the interest of geological features. The prevalence of laterite is discussed; but we should hesitate to say that the iron was "from the first" in the state of hydrous oxide. Glauconite, mentioned in connection with clays, is a silicate and not a phosphate. Are not the cubic pseudomorphs in the argillites (p. 11) more likely to have been originally pyrite than rock-salt? The author introduces (p. 36) a useful geographical term, *arena*, for undulating areas more or less completely surrounded by hill-ranges. These areas are shown to result from the denudation of domes of strata, and rivers run through the surrounding walls. The Woolhope inlier may thus be called an arena, and numerous examples occur in the