1 and 2 cycles per second. It may be as slow as 0·6 cycle per second; or as fast as 2·5. In asphyxia the rate which obtained at the point of commencement may be triplicated before the attainment of the complete effect. Thus a rate of 1 cycle per second may become one of 3·4. In normal narcosis progression the rate of rhythm may vary considerably in the same individual on different occasions.

Trichromic Vision and Anomalous Trichromatism.

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Definitions.

A. *Trichromic Vision.*

The trichromic in my classification of degrees of colour-perception are those who have only three colour sensations—red, green, and violet. They see only three colours in the bright spectrum and describe it as consisting of red, red-green, green, green-violet and violet. They apply the designation red-green to the orange and yellow regions of the spectrum and green-violet to the blue region.

There are many degrees and varieties of trichromic vision (1, 2, 3, 4, 5). I have classified the colour-perception of individuals as dichromic, trichromic, tetrachromic, pentachromic, hexachromic, and heptachromic. This classification is made by estimating the number of definite colours seen in a bright spectrum, and the persons belonging to each class behave in every way as if they possessed the number of colour sensations indicated. On my theory of colour-vision each colour sensation is separate and distinct and not compounded of two or more fundamental colour sensations. For instance, there is the strongest evidence that yellow is a simple sensation (18, 24, 25, 26) and that spectral yellow light does not excite the red and green sensations.

B. *Anomalous Trichromatism.*

The term anomalous trichromatism is used in the sense of the Young-Helmholtz theory in which all colour sensations are supposed to be made up of different proportions of three fundamental sensations. A trichromat on this theory is therefore a person with normal colour-perception. An

anomalous trichromat is a person who is supposed to have three fundamental sensations but they have not the same proportions as in the normal-sighted. Those are designated anomalous trichromats who, when making the equation $\lambda 670 + \lambda 535 = \lambda 589$, use proportions of red and green different from the normal. At the same time the subjects of this abnormality object to the normal equation. Those who put too much red in the mixed colour are called red-anomalies and those who put too much green in the mixed colour green-anomalies.

Anomalous trichromatism was discovered by Lord Rayleigh (6), who stated that the colour vision is defective only in the sense that it differs from that of the majority. In 1904 Guttmann (8) stated that the anomalous trichromats were colour weak and described a number of symptoms similar to those given by me as associated with trichromic vision.

I then examined a number of persons with Rayleigh's apparatus (14) and found that many colour-blind persons, both dichromic and trichromic, can make a match which agrees in every particular with that of a normal sighted person.

I could find no evidence that colour weakness was necessarily associated with anomalous trichromatism. I examined 15 students from Newnham College on the same afternoon, the conditions being precisely the same for each. There was considerable variation in the observations and those who made an anomalous equation in every case strongly objected to the normal match. I could find no evidence of colour-blindness in any of those examined. All saw yellow in the spectrum. Of the 15 examined, five made the normal match exactly and one required slightly more green, the others more red in proportions varying in different cases; there was considerable difference between the two extremes, one requiring nearly twice as much red as the other in the mixed colour.

This year Lord Rayleigh kindly lent me his colour-mixing apparatus and I examined 100 women students, 25 belonging to the London County Council training college and 75 to University College. The last 75 were examined in precisely similar conditions. The illumination was incandescent electric light and the equation did not vary from day to day. All were examined with Lord Rayleigh's colour-mixing apparatus; 51 were examined by some kind of test for colour-blindness, and 36 of these were examined by my lantern. I have designated as "anomalies" those who, on an average of a number of observations, had a deviation of more than one whole division from the normal and did not agree with the normal equation. The colour-mixing instrument of Rayleigh was arranged so that 0 corresponded to full red and 25 to full green. Then by the laws of double refraction the exact proportions of red

and green in any mixture can be ascertained. For instance, 12·73 corresponds to a ratio of intensity 1·061 green/red, and 10·371 to 0·5829 green/red. The other figures can be easily understood by remembering that a difference of one-tenth of a division corresponds to a difference of about 2½ per cent. in the ratio of intensities of red to green when the figures are in the neighbourhood of normal vision.

Out of the hundred examined, 86 made the normal equation or within one division on either side of it, 12 were anomalous trichromats, 10 being red-anomalies and 2 being green-anomalies.

Red-anomalies.				Green-anomalies.	
1.	1·5	6.	1·2	1.	3·1
2.	1·4	7.	1·8	2.	1·3
3.	1·2	8.	2·5		
4.	1·5	9.	1·3		
5.	1·3	10.	1·3		

Two others on an average of five observations appeared as anomalies (one 1·3 red, the other 2·0 green), but, as they both agreed with the normal equation, they do not come under the definition.

Excluding the last mentioned, who were to a certain extent colour blind, none of the anomalies were found to be colour defective. Of those who made the normal match 9 were found to be colour defective.

No. 1 of the green-anomalies was examined very carefully on three occasions; there was no evidence of colour-blindness; she passed my ordinary lantern test and also my triple lantern with ease and accuracy, and saw red and green through small apertures as far as I did. She also passed my bead test.

Examination with Spectrometer.—Pure yellow was isolated at λ 5770 to λ 5882. This is quite normal. The area of greatest luminosity was λ 5697 to λ 5795; this is considerably to the green side of the maximum of the normal luminosity curve. She marked out 18 monochromatic divisions in the spectrum. This is the normal number; she also named all the colours red, orange, yellow, green, blue, and violet correctly.

I have also examined a large number of men and find that when there is a large mean deviation there is colour weakness. The following case is instructive as an example of a high grade green-anomaly without any trace of colour weakness.

The observer was an assistant in the Chemical Laboratory of the Physiological Institute, University College.

Rayleigh Apparatus.—Shown red and yellow, named them correctly as red and yellow. The mean of seven equations was 17·3, the mean deviation 0·1.

The normal equation was 14·5. The mean deviation is very small.

Strongly objected to the normal equation ; said that the mixed colour was orange, and the simple, yellow.

Nagel's Test and Stilling's Test.—Passed both these tests with much greater ease and more rapidly than most normal-sighted persons.

My Lantern Test.—Passed easily.

The above tests were made in the presence of Prof. Starling and Dr. Homans.

Spectrometer.—

Region of greatest luminosity..... λ 589–λ 605
„ pure yellow ..... λ 591–λ 596·5

My yellow region λ 583–λ 590 appeared greenish-yellow to him. This region inclines to orange-yellow to me.

Pure blue was λ 472–λ 476. Pure green, λ 510–λ 514.

Simultaneous contrast was not more marked than normal. Saw red below λ 780.

The following are the monochromatic regions marked out by him:—

	μμ.				μμ.		
1.	λ 780 – 1	Called by him	Red.	14.	λ 503 – 1	Called by him	Green-blue.
2.	λ 626 – 1	„	Orange.	15.	λ 497 – 1	„	„
3.	λ 613·5 – 1	„	Orange-yellow.	16.	λ 491 – 1	„	Blue.
4.	λ 605 – 1	„	Yellow.	17.	λ 483·5 – 1	„	Deep blue.
5.	λ 597 – 1	„	Greenish yellow.	18.	λ 475 – 1	„	Violet-blue.
6.	λ 590 – 1	„	„ „	19.	λ 466·5 – 1	„	Blue-violet.
7.	λ 579 – 1	„	Yellow-green.	20.	λ 457 – 1	„	„
8.	λ 567 – 1	„	„	21.	λ 447 – 1	„	Violet.
9.	λ 558 – 1	„	„	22.	λ 435 – 1	„	„
10.	λ 541 – 1	„	Green.	23.	λ 426 – 1	„	„
11.	λ 523 – 1	„	Blue-green.	24.	λ 417 – 1	„	„
12.	λ 516 – 1	„	„	25.	λ 411 – 1	„	„
13.	λ 509 – 1	„	Green-blue.		λ 407		

It will be noticed that the region regarded by the normal-sighted as orange-yellow is named and seen by him as greenish yellow. This gives an explanation of the anomalous trichromatism. If the region to be matched appears greener than usual, it will obviously require more green and less red in the mixed colour.

These were the results of single observations ; the available time would not admit of more and they clearly confirm the other tests.

The Relation between Trichromic Vision and Anomalous Trichromatism.

Anomalous trichromatism should be clearly defined as the condition in which anomalous matches are made by a person who refuses to accept the normal match. Much confusion exists on this point; a person who agrees with the normal equation cannot be regarded as an anomalous trichromat even though he agrees at the same time with the anomalous matches. This is only evidence of colour weakness, inasmuch as both equations are regarded as satisfactory. There are many anomalous trichomats who are not colour weak and there are many trichromics who make absolutely normal equations. Trichromic vision in my classification is therefore not synonymous with anomalous trichromatism. There are also persons who will make the normal equation in one set of circumstances and anomalous equations in another (14). There are also those who will make normal equations when the red employed is λ 670 but will make an anomalous equation with a red of larger wave-length, as for instance λ 690, putting twice as much red in the mixture compared with the normal equation in similar circumstances (16). Anomalous trichromatism when too much red is put in the mixed colour may correspond to defect in the perception of certain red rays, namely those employed in the mixed colour. I have shown (5) that when there is shortening or much defect in the perception of red the junctions of the other colours are shifted towards the violet end of the spectrum. The yellow, therefore, corresponding to the D line, is seen as a much redder colour than the normal, and if we consider that the green is similar to the normal it is obvious that more red will be put in the mixture than by the normal-sighted. This shortening of the spectrum may be associated with normal vision in other respects or with any degree of defective colour differentiation, that is to say, it may be associated with dichromic, trichromic, tetrachromic, pentachromic, hexachromic or heptachromic vision. A similar condition is also found for the violet end of the spectrum. It is obvious that a man, who has shortening of the red end of the spectrum or defect in the perception of red, is colour weak as far as red is concerned. Unless, however, he has defective hue perception he may make no other error than that directly connected with the defective perception of certain red rays. It is different with those who make an anomalous match in which too much green is put in the mixed colour. As found by Rayleigh (6), Köllner (20), v. Kries (10), Nagel (13), and myself (14), a man may make an anomalous match without presenting any other colour defect. I have found 25 per cent. of men to be more or less colour weak, and it is, therefore not surprising that anomalous trichromatism

is frequently associated with colour weakness. The colour weak are also particularly liable to fail in making an equation, but in addition to making the anomalous equation they are in most cases satisfied with that of the normal. Anomalous trichromatism cannot be due to the diminution of a green sensation in the sense of the Young-Helmholtz theory. Apart from the fact that I have shown that yellow is a simple and not a compound sensation (18, 24, 25, 26), there would be no reason why more green should be required in making the compound yellow, since the simple yellow would also contain less of the hypothetical green sensation. If whilst the yellow remains as in the normal the sensitiveness to green light were diminished or to red increased we should have an explanation of the facts. Schuster (19) found that the position selected as pure yellow was the same with the green-anomaly as with the normal-sighted. Whilst there are red-anomalies who show weakness for red, there are others who do not, and this may be explained by an increased sensitiveness to green whilst the red and yellow remain as in the normal.

SUMMARY.

1. Trichromic vision is not synonymous with anomalous trichromatism.

2. Many persons with otherwise normal colour-perception make an anomalous equation.

3. Many colour-blind persons (dichromics and trichromics) make an absolutely normal match with no greater mean deviation than the normal.

4. Colour weakness is not characteristic of anomalous trichromatism but of trichromic vision.

5. Anomalous trichromatism and colour weakness are not synonymous.

6. A large mean deviation indicates colour weakness.

7. Anomalous trichromatism appears to be due to an alteration in the normal relations of the response to the three colours (lights) used in the equation. If the eye be more or less sensitive to one of the components of the mixed colour whilst the other has its normal effect, an anomalous equation will result. An anomalous equation will also result when the yellow is more allied to green or red than is normal.

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