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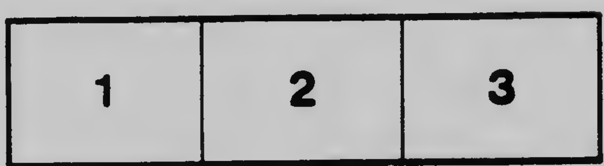

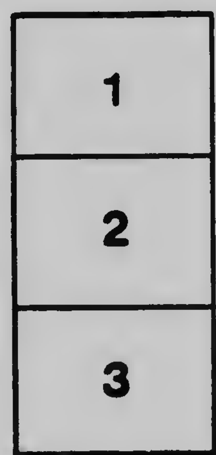

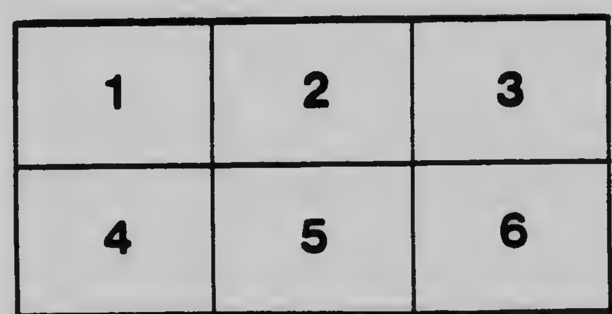

UNIVERSITY OF TORONTO STUDIES

PSYCHOLOGICAL SERIES

VOL. III, No. 1: COMPLEMENTARISM, PHYSICAL AND PSYCHICAL. BY D. S. DIX

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COMPLEMENTARISM: PHYSICAL AND PSYCHICAL

BY

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COMPLEMENTARISM: PHYSICAL AND PSYCHICAL

I.

COMPLEMENTARISM AND COLOUR THEORIES

Complementarism forms a field of investigation for both the physicist and the psychologist, but its significance for each must be sharply distinguished. All physics is based in the last analysis not upon the directly given facts, but upon the results of constructive abstraction. Sound, light, heat, etc., physically regarded, are merely waves of ether (or ponderable matter), of certain length and amplitude, acting upon the respective physical organs. Thus, the problem of complementary colours is for the physicist the relation of two sets of waves, each of which would produce a certain colour-quality, but which, in combination, give a quality totally different from either, colourless light.

Whatever psychology may have been in the past, to-day it can justly claim to be a science, for it seeks to investigate the facts of the given world, the world of consciousness. Its field is the same as that of the so-called natural sciences, its methods also being the same, i.e., observation and experiment. But the essential difference consists in this, that psychology finds its subject matter in the facts as they are given, while the natural sciences build upon hypotheses deduced from these facts. But the facts from which they start are the same for both. It is, therefore, plain that only the interpretation of an experiment will determine whether it is physical or psychical in its significance. Psychology maintains that "if the results of science shall have certainty, then science must begin with the elementary facts of consciousness, and not with contradictory pseudo-conceptions."* Thus physical optics, to be more than a merely kinetic discipline, must begin with a rigid analysis of the facts of light and colour. Modern optics does not do this, and as it also fails to accept the psycho-physical laws in its theory of light, so psychology must decline to make physical ideas the basis in an analysis of the facts of sensation and in its theory of visual

* Kirschmann, *Dunkles im Gebiete des Lichts* (Bericht über den II. Kongress für Experimentelle Psychologie, p. 229.)

qualities. Psychically, there are no mixed colours, for sensations, or sense-qualities, do not mix. Whether the nature of the organism will afford an explanation of the lack of parallelism between the stimulus and the sensation is another question. In the meantime we observe that for the physicist colour-qualities and colour phenomena are quantitative functions of wave-lengths, while for the psychologist these sensations are the subject of qualitative and quantitative investigation. And, as Kirschmann has pointed out*, any adequate description of the manifoldness of light qualities and their phenomena (e.g., complementarism) must be based on the real attributes and conditions of sensation.

Furthermore, it may be said that the exact ascertainment of the complementary relations of colours has practically no meaning at all for the physicist; for thus far no fixed relation has been found between what he regards as colour (i.e., wave-length) and complementarism. With the help of a chart of the normal spectrum, it is found that the change in colour-quality in different parts is not directly proportional to the change in wave-length. So, too, Helmholtz has found that the relation which does exist is not a fixed one for all the different pairs of complementary colours, but that it varies considerably. The following table exhibits this variation as Helmholtz† ascertained it (the unit of length used being the micron):

Colour	Length of Wave	Complementary Colour	Length of Wave	Relation of Wave-Lengths of Complementaries
Red	656.2	Greenish Blue	492.1	1.334
Orange	607.7	Blue	489.7	1.240
Golden Yellow ..	585.3	Blue	485.4	1.206
Golden Yellow ..	573.9	Blue	482.1	1.190
Yellow	576.1	Indigo Blue	464.5	1.221
Yellow	564.4	Indigo Blue	461.8	1.222
Green-Yellow	563.6	Violet	433 and onward	1.301

* Kirschmann, *Normale und Anomale Farbensysteme* (Archiv für die gesamte Psychologie, Band VI., p. 397.)

† Helmholtz, *Physiological Optics*, p. 317.

The statements of various observers differ very much. Thus for von Kries the complementary for 556.2 $\mu\mu$ is 492.4 $\mu\mu$; for von Frey it is 485.2 $\mu\mu$. The complementary for 570.1 $\mu\mu$ for von Kries is 429.5; for von Frey this is the complementary of 566.4 $\mu\mu$, whilst the complementary for 570.1 $\mu\mu$ must be above 460 $\mu\mu$ for him.

The discrimination of changes of colour-tone in the spectrum is absolutely independent of the numerical relations of

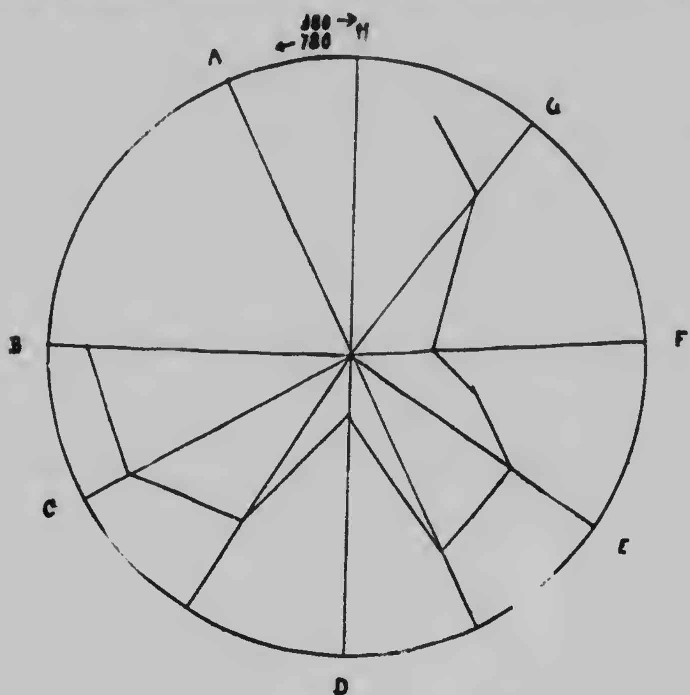

FIG. 1.

wave-lengths and vibration-frequency. In Fig. 1, we represent the spectrum by the circumference of the circle as abscissæ, and the discriminative sensibility for colour-tone, as ascertained by Dobrowolsky*, as the ordinates. Thus we get a curve which

* Archiv für Ophthalmologie, Bd. 18, I. *Vide* Wundt, *Physiologische Psychologie*, Vol. II., p. 144.

reaches its first maximum in the yellow, near D, and its second in the blue, near F; while the two minima are found in yellow-green and violet. The three sections in this curve nearest to the circle correspond to the beginning, the middle, and the end of the visible spectrum.

Many efforts have been made by physicists to account for the facts, the most generally accepted theory being the Young-Helmholtz theory, which starts from the existence of three primary colour-qualities—red, green, and violet. It is argued that since the mixture of these in right proportions gives all the colour-qualities at a relatively great degree of saturation, therefore there are three elementary stimulations and three primary sensations corresponding to them. These stimulations are made possible by the functions (according to Young) of three kinds of nerve-fibrils, or (according to Helmholtz) of three chemical substances. The sensation of red is the result of the stimulation of one; the sensation of green the result of another; and violet of a third. Now, light excites all three of these nerve-fibrils or substances, but with different intensity, according to the wave-length. Every colour-sensation, then, peripherally excited, means a certain "mixture" of these three elementary stimulations.

According to this view, the sensation of white means that these three kinds of nerve-fibrils or substances are stimulated to about the same degree of activity. But the facts of complementarism show that two so-called "colours" stimulate all the three sets of nerves, or substances, as effectually as the three fundamental ones. It is this fact, among others, that the physicist is called upon to explain, and Rood* attempts to elaborate the theory so as to account for this as follows:

"Red and green-blue are complementary colours, because red light stimulates the red nerves, and green-blue light both the green and the violet nerves; the joint action of the three sets gives white light. Orange and cyan-blue is the next pair: orange light sets in action the red nerves powerfully, also somewhat the green nerves; cyan-blue sets in action the green and the violet nerves; all three sets of nerves acting, the result is the sensation of white. The case is much the same with yellow and genuine ultramarine-blue: both colours stimulate two sets of nerves; that is, the yellow acts on the red and green nerves, the blue on the green and violet nerves. With green

* Rood, *Text-Book of Colour or Modern Chromatics*, p. 176.

and purple the first colour acts, of course, on its own set of nerves, the second on the red and violet nerves."

Furthermore Rood* maintains, in defence, that this theory "enables us to understand a fact which otherwise might appear quite strange, viz., that if we take away from white light any colour, the light which remains will have the complementary hue. Thus if we strike out from white light the orange rays, the remainder will appear of a rather pale cyan-blue. The table of complementary colours explains this result; thus

Red and green-blue	make..........white
Orange and cyan-blue	make..........white
Yellow and blue	make..........white
Green-yellow and violet	make..........white
Green and purple	make..........white

All these five pairs of colours are present in white light. If we remove from it orange, then cyan-blue is the only colour which is not neutralized; all the other colours balance up and make white light which mixes with and pales the uncombined cyan-blue. The explanation is the same in the other cases. It follows from this that the complementary colours produced by the method of striking out a colour are rendered rather pale by the presence of a considerable amount of white light. This is the reason why the complementary colours obtained by the use of polarized light are always rather pale."

This theory can be shown to be wrong by a simple experiment with the so-called inverted spectrum, whose colours can all be regarded as derived by the subtraction of one part of the ordinary spectrum, and which yet show a saturation† by no means inferior to that of the ordinary spectrum. Especially do the blue and the yellow show a beauty and saturation they never have in the ordinary spectrum; and the qualities between blue and red (i. e., the violets and purples) are, with regard to saturation, not inferior to any part of the ordinary spectrum.

The theory as a whole is weak, because it ignores certain facts, experimentally ascertained, and which are of the utmost importance in the formulation of a theory of vision. For example, there is no recognition of the independence of the brightness component in a colour impression, a view which is sufficiently upheld by the phenomena of colour-blindness, and of the pure brightness quality which accompanies very brief or intense stimulation. Aside from the fact that physicists should be able to agree as to what qualities *are* fundamental, there is no

* Ibid, p. 177.

† Cf. Kirschmann's discussion of Saturation in American Journal of Psychol., Vol. VII., p. 395, and in Archiv für die gesamte Psychologie, Vol. VI., p. 399.

reason to accept the term "primary sensation" as anything but arbitrary, since all other colour-qualities are as elementary as those chosen. It is by no means a necessary basis that all sensations be correlated with equally elementary processes.

On the other hand, when the phenomena of light and colour are recognized, adherents of this theory frequently resort to improbable and arbitrary hypotheses. This seems to characterize Rood's effort to explain the facts of complementarism. But five indefinitely stated pairs are cited in illustration. No effort is made to show, for example, how red and green-blue as complementaries may stimulate the nerve-fibrils to "about the same degree of activity." The explanation leads only to more indeterminate ideas as to the meaning of "primary sensation." But, even if there should be found an exact quantitative relation of wave-lengths to shed light upon the facts of complementarism (which, so far, has not been done), we should still have no adequate ground for speaking of the phenomenon as a function of wave-length. Every chance of finding a definite physical relation of wave-lengths which corresponds to complementarism will vanish if we accept the consequences of the fact that complementarism changes with a different tuning of the sense-organ, and that for certain colour-blinds* colours are complementary which for the normal eye are not. This has even been made out in a case of monocular dichromatism, where for the left (normal) eye the usual relations of complementaries obtained, whilst for the right eye the red of about 650 $\mu\mu$ and the blue of 477 $\mu\mu$ acted as complementaries and contrasting antagonists.

The time required for the origination of a visual sensation and the duration of the after-effect of a stimulation have suggested to some that the explanation of the process requires greater emphasis to be laid on the chemical side. So these see complementarism largely as a chemical function. Perhaps the most lucid theory from this physiological and chemical point of view is that of Hering.† This, too, starts out with the assump-

* Kirschmann in Philosophische Studien, Vol. VIII., p. 196, also in Archiv für die gesamte Psychologie, Vol. VI., p. 413. See also Wundt, *Physiologische Psychologie*, Vol. II., p. 229.

† Hering, *Lehre vom Lichtsinne.*

tion of three visual substances (though no attempt is made to localize them), and the fundamental sensations are not three, but six—black and white, red and green, blue and yellow. Each of these three pairs corresponds to an assimilation or dissimilation process in one of the visual substances. Thus red light acts on the "red-green" substance in exactly the opposite way from green light, and when both kinds of light are present in suitable proportions, a balance is effected, and both sensations (red and green) vanish. Thus we have the phenomenon of complementarism. Again, according to this theory, all the colours of the spectrum also affect the black and white substance in the same way that white light does. For example, red light affects the red-green substance and produces the sensation of red, but it also acts on the white-black substance, and the sensation of red is mingled with that of white light. Mixed colours and degrees of brightness, therefore, arise from the preponderance of assimilation and dissimilation in various proportions.

In order to be just to the dependence of quality on intensity (as manifested in Purkinje's phenomenon), Hering introduces the conception of the "White-valenz" of the colours.* In criticism of this, we would say that Hering does not seem to be at all clear as to whether this "White-valenz" is a property of the sensation or of the physiological or physical processes.

There can be no doubt that as a physical theory this takes a more comprehensive survey of the phenomena of light and colour. It evidently is especially designed to explain complementary colours. Yet the complete analogy between the processes in the white-black substance and the two-colour substances has no existence in reality. In Kirschmann's article on saturation†, it is noted that the passage from the deepest black to the highest degree of white is along a continuous series of colourless sensations, but complementary colours pass into each other through an indifference point. This makes it highly improbable that one stage in the assimilating and dissimilating process corresponds to an intermediate grey, while in the case

* Kirschmann, *Normale und anomale Farbensysteme.* (Archiv für die gesamte Psychologie, Vol. VI., p. 402.)

† American Journal of Psychology, Vol. VII., p. 395.

of complementary colours it gives rise to an indifference point. Moreover, how shall we determine just what grey in the series corresponds to this point? Apart from the fact that colour sensation in indirect vision and certain forms of dichromatism are to a great extent unaccounted for by Hering's theory, we may conclude that, while it makes room for complementary colours, it by no means explains them. All purely physical or physiological theories, instead of aiming at the exploration of the processes in consciousness, seek a solution in the constitution of the physical organ. They do not deal with the psychical problem.

II.

EXACT DETERMINATION OF THE COMPLEMENTARY RELATIONS

(a) *Milton-Bradley papers. Full saturation, tints, shades.*
(b) *Hering papers.*
(c) *Prang papers.*
(d) *Spectrally approximately pure colours.*
(e) *Inter-relations between Milton-Bradley, Hering, and Prang systems.*
(f) *Painters' water-colours.*
(g) *Browns especially.*
(h) *Liquid mixtures; ordinary water-colours. Verdin's transparent colours.*

As has been pointed out elsewhere,* complementarism is of great importance to the psychologist, inasmuch as it plays an important rôle in the field of the phenomena of contrast and after-images, as well as in that of colour-blindness. Therefore, it is somewhat remarkable that up to the present we have been satisfied with a very indefinite statement of the complementary relations. Lately the interest in the experimental investigation of aesthetic problems has greatly increased, and, consequently, it

* Kirschmann and Dix, *Experimentelle Untersuchung der Komplementärverhältnisse gebräuchlicher Pigmentfarben.* (Archiv für die gesamte Psychol., Vol. XI., p. 128.)

is for the interpretation of experimentally found facts of the utmost importance that we have exact data. Thus, for example, the statement of the importance of complementarism in harmonic colour combinations is valueless if we have not a sufficiently large number of qualities. Moreover, we must exactly ascertain which other quality of the manifoldness, or what combination of two neighbouring qualities is complementary to that one. The colour pairs which we get by polarization* are complementary, but of such complexity that the complementary relation is of little value. It is very unlikely that the determination of the complementarism of spectral colours would be of any practical benefit, for in practice we have mostly to deal with colours, which, though often not less brilliant and intensive than the spectral colours, have not the so-called physical purity of the latter. In arriving at the complementary colours of the spectrum, the solution of the task of equalizing the light intensity and saturation is more or less of an arbitrary character. For these reasons, we have ascertained in a systematic way in the laboratory of the University of Toronto the complementary relations of the best known systems of pigment papers, as well as of the most frequently used water-colours.

Two Marbe's apparatus were used, one with the coloured discs, the other (for comparison) with a black and a white disc. As it is only on rare occasions that there is found among the pigments a pair of exact complementaries, it is usually a combination of three colours that is required. As Marbe's apparatus only permits the variation of the sectors of two components while rotating, the changing of the angle of the third sector had to take place in the old way, i.e., by stopping the apparatus and increasing degree by degree. The experiment was as follows: Both sets of discs (the coloured and the uncoloured) were placed side by side. The coloured sectors were varied until an indifferent grey was reached. Then, by the aid of the second Marbe's apparatus, a grey, composed of the black and white, was found exactly like the other. If the exact likeness could not be found, then the grey of the coloured discs was varied again, until the

* Cf. Rood, *Text-Book of Colour on Modern Chromatics*, pp. 160-171.

exact likeness was obtained. All experiments took place under illumination by diffused daylight. Both sets of discs were seen on a dull, black background, which was opposite the only window in a room with indifferently grey walls. The light admitted came partly from the sky and partly from the grey walls of the opposite wing of the University building.

After the experimentees had acquired the necessary practice, it required at least an hour to obtain an equation, and frequently a much longer period. The numbers given in the following Tables are the average of two double observations (i.e., the observation was made twice by each of two observers). Tables I, II, and III contain results of experiments with the Milton-Bradley system of coloured papers (Table I with full colours; Table II with tints; Table III with shades).

TABLE I.

Milton-Bradley System.

202	R.	+136½	B.G.	+ 21½	G.B.	= 81½	White	+278½	Black
135½	O.R.	+191	B.G.	+ 33½	G.B.	=106	White	+254	Black
113½	R.O.	+199	B.G.	+ 47½	G.B.	=107	White	+253	Black
99	O.	+176	B.G.	+ 85	G.B.	=120	White	+240	Black
105	Y.O.	+122	B.G.	+133	G.B.	=122½	White	+237½	Black
120½	O.Y.	+ 5	B.G.	+234½	G.B.	=138½	White	+222½	Black
138½	Y	+110	G.B.	+111½	B.	=153	White	+207	Black
147	G.Y.	+ 90	B.V.	+123	V.	=136½	White	+223½	Black
126	Y.G.	+186	R.V.	+ 48	V.R.	=139	White	+221	Black
131	G.	+ 48	R.V.	+181	V.R.	= 92	White	+268	Black
142	B.G.	+ 40½	V.R.	+177½	R.	= 84½	White	+275½	Black
240	G.B.	+116	O.Y.	+ 4	Y.	=153½	White	+206½	Black
184½	B.	+ 69	Y.	+106½	G.Y.	=146½	White	+213½	Black
197½	V.B.	+ 43	Y.	+119½	G.Y.	=145½	White	+214½	Black
194	B.V.	+ 16	Y.	+150	G.Y.	=177	White	+183	Black
235	V.	+ 78½	G.Y.	+ 46½	Y.G.	=125½	White	+234½	Black
225½	R.V.	+ 27	G.Y.	+107½	Y.G.	=142	White	+218	Black
228½	V.R.	+105½	G.	+ 26	B.G.	= 91½	White	+268½	Black

TABLE II.

Milton-Bradley System: Tints (No. 2).

120	R.	+ 92	B.G.	+148	G.	=273	White + 87	Black
137	O.R.	+103	B.G.	+120	G.	=281	White + 79	Black
134	R.O.	+126	B.G.	+100	G.	=307	White + 53	Black
132	O.	+149	B.G.	+ 79	G.	=294	White + 66	Black
130	Y.O.	+ 81	B.G.	+149	G.B.	=304	White + 56	Black
146	O.Y.	+197	G.B.	+ 17	B.	=242	White +118	Black
205	Y.	+145	V.B.	+ 10	B.V.	=320	White + 40	Black
196	G.Y.	+135	R.V.	+ 29	V.R.	=222	White +138	Black
196	Y.G.	+ 22	R.V.	+142	V.R.	=287	White + 73	Black
218	G.	+ 75	V.R.	+ 67	R.	=305	White + 55	Black
214	B.G.	+ 76	O.	+ 70	Y.O.	=316	White + 44	Black
205	G.B.	+ 40	Y.O.	+115	O.Y.	=311	White + 49	Black
173	B.	+131	O.Y.	+ 56	Y.	=303	White + 57	Black
161	V.B.	+ 9	O.Y.	+190	Y.	=297	White + 63	Black
171	B.V.	+175	Y.	+ 14	G.Y.	=297	White + 63	Black
172	V.	+ 94	Y.	+ 94	G.Y.	=300	White + 60	Black
167	R.V.	+ 9	Y.	+184	G.Y.	=298	White + 62	Black
157	V.R.	+ 38	Y.G.	+165	G.	=283	White + 77	Black

TABLE III.

Milton-Bradley System: Shades (No. 2).

127	R.	+223	B.G.	+ 10	G.B.	= 33	White +327	Black
84	O.R.	+258	B.G.	+ 18	G.B.	= 37	White +323	Black
87	R.O.	+235	B.G.	+ 38	G.B.	= 38	White +322	Black
68	O.	+251	B.G.	+ 41	G.B.	= 37	White +323	Black
79	Y.O.	+212	B.C.	+ 69	G.B.	= 38	White +322	Black
105	O.Y.	+116	B.G.	+139	G.B.	= 80	White +280	Black
152	Y.	+ 22	B.G.	+186	G.B.	= 98	White +262	Black
198	G.Y.	+ 14	B.V.	+148	V.	= 98	White +262	Black
162	Y.G.	+130	R.V.	+ 68	V.R.	= 81	White +279	Black
117	G.	+ 39	R.V.	+204	V.R.	= 91	White +269	Black
196	B.G.	+ 44	V.R.	+120	R.	= 74	White +286	Black
193½	G.B.	+156	Y.	+ 10½	G.Y.	=105½	White +254½	Black
165	B.	+156	Y.	+ 39	G.Y.	= 89	White +271	Black
194	V.B.	+ 60	Y.	+106	G.Y.	= 70	White +290	Black
166	B.V.	+ 62	Y.	+132	G.Y.	= 95	White +265	Black
158	V.	+187	G.Y.	+ 15	Y.G.	=133	White +227	Black
196	R.V.	+ 71	G.Y.	+ 93	Y.G.	= 82½	White +277½	Black
200	V.R.	+100	G.	+ 60	B.G.	= 73	White +287	Black

For a better survey, we give in Figures 2, 3, and 4 a graphic representation of these Tables. We distribute the qualities of the Milton-Bradley system in equal distances on the periphery of a circle. Then we draw from each of the points which mark the colours a straight line to that point on the periphery where (according to the result in the above Tables) the complementary colour is found. Naturally, the distances of that point from the two neighbouring qualities are in inverse proportion to the numbers found in the above equation.

It will be noticed in all these figures that the lines do not pass through the centre, as would be expected, but form certain triangular figures, which are similar in all three cases. This phenomenon might be due to the following circumstance: The eccentric position of the places of intersection of the lines is caused by the preponderance of the red, orange, and yellow qualities over the others. That the points of intersection cluster around the corners of a triangle is owing to the fact that the pigments which are used in colouring these papers are in all likelihood not so numerous as the system would lead us to believe. Apparently, six different qualities, from red to yellow, were used, and just as many from red to blue. Whereas probably only a few pigments are used, and the qualities lying between are produced by mixture. The change in the qualities is greatest from yellow to green, from green to blue, and from violet to red.

If we compare the three figures, we find, also, a noticeable disarrangement in the complementarism of the tints and shades. This is indicated in Table IV. Whether this disarrangement is caused by Purkinje's phenomenon or by the methods employed to produce the tints and shades in the Milton-Bradley system can hardly be ascertained. Perhaps both factors are responsible. But so much is sure, the tints and shades in the Milton-Bradley system are not exact tints and shades of the colours of the same name.

TABLE IV.

No. of the Colour	Designation of the Colour	The Complementary falls		
		In the full Colours between	In the Tints between	In the Shades between
1	Red	11 and 12	10 and 11	11 and 12
2	Orange Red......	11 " 12	10 " 11	11 " 12
3	Red Orange	11 " 12	10 " 11	11 " 12
4	Orange..........	11 " 12	10 " 11	11 " 12
5	Yellow Orange ..	11 " 12	11 " 12	11 " 12
6	Orange Yellow ..	11 " 12	12 " 13	11 " 12
7	Yellow	12 " 13	14 " 15	11 " 12
8	Green Yellow	15 " 16	17 " 18	15 " 16
9	Yellow Green	17 " 18	17 " 18	17 " 18
10	Green	17 " 18	18 " 1	17 " 18
11	Blue Green	18 " 1	4 " 5	18 " 1
12	Green Blue	6 " 7	5 " 6	7 " 8
13	Blue	7 " 8	6 " 7	7 " 8
14	Violet Blue	7 " 8	6 " 7	7 " 8
15	Blue Violet	7 " 8	7 " 8	7 " 8
16	Violet	8 " 9	7 " 8	8 " 9
17	Red Violet	8 " 9	7 " 8	8 " 9
18	Violet Red	10 " 11	9 " 10	10 " 11

In Table V, and the corresponding Figure 5, we give in the same way the complementary relations of Hering's colours, as procured from Mr. Rothe. Similarly, also, Table VI gives the results of experiments with the Prang Standard System of Educational Colour Papers. It may be mentioned that the investigations of the full colours of the Milton-Bradley and Hering papers were carried on by Messrs. D. S. Dix and D. C. McGregor,* and those of the tints and shades by Messrs. T. W. Murphy and L. E. Davis. The equations of Table VI are the results of experiments by Messrs. J. E. Gibson and H. R. Pickup. Figure 6 gives a graphical representation of these experiments, corresponding to the other figures.

In Table VII and Figure 7 we give for comparison the results of experiments performed seven years ago by Miss

* University of Toronto Studies: Psychological Series, Vol. II, No. 2.

Baker and Professor Kirschmann* (by the usual method, with out the Marbe's apparatus). They correspond exactly, witl some few exceptions. The exceptions between violet an red can probably be accounted for by the fact that the Prang colours supplied were not identical during the period of seve years. Small differences, especially in the region of red-violet have frequently been noticed in different sets of papers obtaine for the laboratory.

TABLE V.

Hering System.

	R. I.	+101½	G.B.	+117	B.G.	= 72	White +288	Black
	R. II.	+117	G.B.	+122	B.G.	= 83	White +277	Black
118½	O.R.	+134	G.B.	+107½	B.G.	= 74½	White +285½	Black
87	O.	+188½	G.B.	+ 84½	B.G.	= 88½	White +271½	Black
99	O.Y.	+ 33½	B.	+227½	G.B.	= 93½	White +266½	Black
119	Y.	+177½	B.	+ 63½	G.B.	=110½	White +249½	Black
154	Y.G.	+ 87½	V.R.	+118½	V.	= 80½	White +279½	Black
161	G.	+149½	V.R.	+ 49½	V.	= 67½	White +292½	Black
185	B.G.	+102½	V.R.	+ 72½	R. I.	= 77½	White +282½	Black
262½	G.B.	+ 56	O.Y.	+ 41½	O.	= 89½	White +270½	Black
210	B.	+107	Y.	+ 43	Y.G.	=101	White +259	Black
216	V.	+ 51½	Y.	+ 92½	Y.G.	= 94½	White +265½	Black
183½	V.R.	+ 92	B.G.	+ 84½	G.	= 70	White +290	Black

* University of Toronto Studies: Psychological Series, Vol. I, No. 4.

TABLE VI.

The Prang Standard System of Educational Colours.

(1)	85	R.	+137	G.B.G.	+138	B.G.	= 45	White+315	Black
(2)	80	R.R.O.	+112	G.B.G.	+168	B.G.	= 43	White+317	Black
(3)	63	R.O.	+ 73	G.B.G.	+224	B.G.	= 38	White+322	Black
(4)	48	O.R.O.	+ 22	G.B.G.	+290	B.G.	= 36	White+324	Black
(5)	45	O.	+315	B.G.			= 31	White+[illegible]	Black
(6)	48	O.Y.O.	+252	B.G.	+ 60	B.B.G.	= 62	White+29[illegible]	Black
(7)	60	Y.O.	+200	B.G.	+100	B.B.G.	= 65	White+295	Black
(8)	75	Y.Y.O.	+ 95	B.G.	+190	B.B.G.	= 90	White+270	Black
(9)	130	Y.	+102	B.B.G.	+128	B.	=128	White+232	Black
(10)	80	Y.Y.G.	+280	V.			= 75	White+285	Black
(11)	75	Y.G.	+120	V.	+165	V.R.V.	= 33	White+327	Black
(12)	88	G.Y.G.	+ 37	V.	+235	V.R.V.	= 30	White+330	Black
(13)	95	G.	+265	V.R.V.			= 35	White+325	Black
(14)	180	G.B.G.	+180	R.V.			= 39	White+321	Black
(15)	315	B.G.	+ 45	O.			= 40	White+320	Black
(16)	270	B.B.G.	+ 70	Y.Y.O.	+ 20	Y.	= 85	White+275	Black
(17)	210	B.	+130	Y.	+ 20	Y.Y.G.	=141	White+219	Black
(18)	225	B.B.V.	+ 85	Y.	+ 50	Y.Y.G.	= 82	White+278	Black
(19)	266	B.V.	+ 40	Y.	+ 54	Y.Y.G.	= 70	White+290	Black
(20)	267	V.B.V.	+ 34	Y.	+ 59	Y.Y.G.	= 78	White+282	Black
(21)	285	V.	+ 75	Y.Y.G.			= 74	White+286	Black
(22)	255	V.R.V.	+105	G.			= 35	White+325	Black
(23)	180	R.V.	+180	G.B.G.			= 37	White+323	Black
(24)	145	R.R.V.	+125	G.B.G.	+ 90	B.G.	= 27	White+333	Black

TABLE VII.

(1)	111	R.	+103	G.B.G.	+146	B.G.	= 32	White+328	Black
(2)	81	R.R.O.	+103	G.B.G.	+182	B.G.	= 41	White+319	Black
(3)	72	R.O.	+105	G.B.G.	+183	B.G.	= 45	White+315	Black
(4)	62½	O.R.O.	+297½	B.G.			= 47	White+313	Black
(5)	66½	O.	+152½	B.G.	+ 41	B.B.G.	= 55	White+305	Black
(6)	63	O.Y.O.	+213	B.G.	+ 84	B.B.G.	= 57	White+303	Black
(7)	79	Y.O.	+148½	B.G.	+132½	B.B.G.	= 72	White+288	Black
(8)	94½	Y.Y.O.	+ 23½	B.G.	+242	B.B.G.	= 86	White+274	Black
(9)	128	Y.	+115	B.B.G.	+117	B	=120	White+240	Black
(10)	83	Y.Y.G.	+277	V.			= 71	White+289	Black
(11)	105	Y.G.	+ 33	V.	+222	V.R.V.	= 45	White+295	Black
(12)	132	G.Y.G.	+101	V.R.V.	+127	R.V.	= 58	White+302	Black
(13)	171	G.	+ 57	V.R.V.	+132	R.V.	= 50	White+310	Black
(14)	235	G.B.G.	+ 45	R.V.	+ 80	R.R.V.	= 45	White+315	Black
(15)	294	B.G.	+ 66	O.R.O.			= 53	White+307	Black
(16)	270	B.B.G.	+ 72	Y.Y.O.	+ 18	.Y.	= 83	White+277	Black
(17)	192	B.	+138	Y.	+ 40	Y.Y.G.	=127	White+233	Black
(18)	218	B.B.V.	+100	Y.	+ 42	Y.Y.G.	=120	White+140	Black
(19)	257	B.V.	+ 70	Y.	+ 33	Y.Y.G.	= 87	White+273	Black
(20)	283	V.B.V.	+ 37	Y.	+ 40	Y.Y.G.	= 64	White+296	Black
(21)	272	V.	+ 88	Y.Y.G.			= 74	White+286	Black
(22)	251	V.R.V.	+ 62	Y.G.	+ 47	G.Y.G.	= 65	White+295	Black
(23)	172	R.V.	+138	G.	+ 50	G.B.G.	= 39	White+321	Black
(24)	107	R.R.V.	+246	G.B.G.	+ 7	B.G.	= 45	White+315	Black

It has already been remarked above that the irregular distribution of the complementaries (i.e., the relative accumulation in three regions of the colour circle—yellow, blue-green, and red-violet), and consequently the three-cornered shape of the region of intersection of the lines in the figures is not an attribute of the qualities of sensation, but rather of the pigments which are used in making the papers. This is easily demonstrated in Figure 8. This figure represents the complementary relations of twelve colours, which were obtained by illumination of the

Prang papers, with filtered and more or less monochromatic light (by a method described elsewhere*).

In the following Table (VIII) we give the results of the spectroscopic investigation of these colours. The method of the investigation of these complementary relations is explained in the second article by Dr. Baker.† Figure 8 shows at first glance that in these spectrally pure colours the irregularity of the distribution in the colour circle is eliminated. The triangle has disappeared, and the points of intersection of the lines which join the complementaries are concentrated on a relatively small surface. This, on account of the equalization of the saturation, naturally cannot be in the centre. All the colours were brought to the same light intensity.

TABLE VIII.

Colour	Small opening of Slit		Wide opening of Slit	
	Visible Part of the Spectrum in $\mu\mu$	Greatest Light Intensity	Visible Part of the Spectrum in $\mu\mu$	Greatest Light Intensity
Red	665 —592·5	635 —610	672·5—580	657·5—615
Orange Red	622·5—582·5	612·5—592·5	635 —580	622·5—592·5
Orange	607·5—552·5	585 —562·5	622·5—547·5	607·5—562·5
Orange Yellow	587·5—547·5	562·5—557·5	617·5—537·5	602·5—555
Yellow	580 —512·5	562·5—535	615 —492·5	587·5—555
Yellow Green	565 —497·5	535 —525	580 —480	555 —530
Green	542·5—492·5	530 —507·5	570 —480	537·5—517·5
Green Blue	525 —472·5	512·5—495	550 —447·5	525 —502·5
Blue	510 —460	492·5—475	535 —445	512·5—492·5
Violet	482·5—432·5	470 —462·5	497·5—430	[illegible] —455
Violet Purple	687·5—665 485 —440	462·5—455	700 —665 487·5—430	470 —452.5
Purple	680 —645 480 —430		680 —635 497·5—430	475 —460

That the complementarism of the three systems of pigment papers might be still more definitely related, we proceeded to

* University of Toronto Studies: Psychological Series, Vol. I, pp. 24 *et seq.*

† University of Toronto Studies: Psychological Series, Vol. II, pp. 27 *et seq.*

find the complementary relation of each separate colour-quality in each of the other two systems. Tables IX and X contain the statements of the complementary relations of the Milton-Bradley colours in the Hering and Prang systems respectively, while Figures 9 and 10 are pictorial representations of these relations. Similarly, Tables XI and XII are statements of the complementary relations of the thirteen colour-qualities of the Hering papers in the Milton-Bradley and Prang systems respectively, while Figures 11 and 12 exhibit these relations graphically. And, finally, the results of the similar experiments for the Prang system with the Milton-Bradley and the Hering papers are shown in Tables XIII and XIV respectively, and are diagrammatically presented in Figures 13 and 14. The outer circle in each instance represents the manifoldness of the colour-qualities in the system whose complementaries we seek to find. The colour numbered 1 in each system is placed to correspond to the similar number in the other papers. This was, of necessity, an arbitrary arrangement for diagrammatic purposes.

TABLE IX.

Milton-Bradley.		*Hering Complementory.*					*Intensity.*	
184½	R.	+106½	B.G.	+ 69	G.B.	= 47	White+313	Black
107½	O.R.	+124	B.G.	+128½	G.B.	= 55	White+305	Black
98½	R.O.	+108½	B.G.	+153	G.B.	= 62	White+298	Black
85	O.	+ 67½	B.G.	+207½	G.B.	= 72	White+288	Black
97	Y.O.	+ 10	B.G.	+253	G.B.	= 78	White+282	Black
104	O.Y.	+193	G.B.	+ 63	B.	= 86	White+274	Black
120	Y.	+100	G.B.	+140	B.	= 89	White+271	Black
157	G.Y.	+143	B.	+ 60	V.	= 91	White+269	Black
127	Y.G.	+163	V.	+ 70	V.R.	= 73	White+287	Black
143	G.	+ 45	V.	+172	V.R.	= 53	White+307	Black
210	B.G.	+126	R. I.	+ 24	R. II.	= 75	White+285	Black
230	G.B.	+130	O.Y.			= 99	White+261	Black
201½	B.	+147	Y.	+ 11½	Y.G.	=117	White+243	Black
208	V.B.	+118	Y.	+ 34	Y.G.	=100	White+260	Black
186	B.V.	+ 96	Y.	+ 78	Y.G.	=123	White+237	Black
223	V.	+ 54	Y.	+ 83	Y.G.	= 93	White+267	Black
200	R.V.	+ 30	Y.	+130	Y.G.	= 94	White+266	Black
234	V.R.	+110	G.	+ 16	B.G.	= 56	White+304	Black

TABLE X.

Milton-Bradley.			*Prang Complementary.*				*Intensity.*	
131	R.	+ 174	G.B.G.	+ 55	B.G.	= 52	White+308	Black
70	O.R.	+ 185	G.B.G.	+ 105	B.G.	= 60	White+300	Black
64	R.O.	+ 180	G.B.G.	+ 116	B.G.	= 54	White+306	Black
52	O.	+ 68	G.B.G.	+ 240	B.G.	= 56	White+304	Black
54	Y.O.	+ 282	B.G.	+ 24	B.B.G.	= 50	White+310	Black
82	O.Y.	+ 59	B.G.	+ 219	B.B.G.	= 92	White+268	Black
115	Y.	+ 71	B.B.G.	+ 74	B.	= 109	White+251	Black
78	G.Y.	+ 267	V.	+ 15	V.R.V.	= 81	White+279	Black
57	Y.G.	+ 148	V.	+ 155	V.R.V.	= 50	White+310	Black
60	G.	+ 24	V.	+ 276	V.R.V.	= 33	White+327	Black
95	B.G.	+ 18	R.V.	+ 247	R.R.V.	= 52	White+308	Black
244	G.B.	+ 116	Y.Y.O.			= 142	White+218	Black
195	B.	+ 124	Y.	+ 41	Y.Y.G.	= 155	White+205	Black
206	V.B.	+ 79	Y.	+ 75	Y.Y.G.	= 144	White+216	Black
202	B.V.	+ 54	Y.	+ 104	Y.Y.G.	= 145	White+215	Black
248	V.	+ 7	Y.	+ 105	Y.Y.G.	= 122	White+238	Black
205	R.V.	+ 40	Y.Y.G.	+ 15	Y.G.	= 120	White+240	Black
181	V.R.	+ 15	G.Y.G.	+ 164	G.	= 66	White+294	Black

TABLE XI.

Hering.			*Milton-Bradley Complementary.*				*Intensity.*	
152	R. I.	+ 11	G.	+ 197	B.G.	= 68	White+292	Black
133	R. II	+ 7	G.	+ 220	B.G.	= 75	White+285	Black
129	O.R.	+ 215	B.G.	+ 16	G.B.	= 75	White+285	Black
91	O.	+ 175	B.G.	+ 94	G.B.	= 84	White+276	Black
130	O.Y.	+ 230	G.B.			= 96	White+264	Black
153	Y.	+ 30	G.B.	+ 177	B.	= 109	White+251	Black
139	Y.G.	+ 109	R.V.	+ 112	V.R.	= 85	White+275	Black
129	G.	+ 15	R.V.	+ 216	V.R.	= 65	White+295	Black
154	B.G.	+ 95	V.R.	+ 111	R.	= 64	White+296	Black
265	G.B.	+ 80	Y.O.	+ 150	O.Y.	= 76	White+284	Black
197	B.	+ 46	Y.	+ 117	G.Y.	= 98	White+262	Black
215	V.	+ 75	G.Y.	+ 70	Y.G.	= 80	White+280	Black
195	V.R.	+ 105	G.	+ 60	B.G.	= 56	White+304	Black

TABLE XII.

Hering		*Prang*		*Complementary.*		*Intensity.*	
95	R. I.	+241	G.B.G.	+ 24	B.G.	= 56	White+304 Black
63	R. II.	+233	G.B.G	+ 64	B.G	= 62	White+298 Black
75	O.R.	+ 96	G.B.G.	+189	B.G.	= 46	White+314 Black
44	O.	+ 27	G.B.G.	+289	B.G.	= 55	White+305 Black
92	O.Y.	+128	B.G.	+140	B.B.G.	= 60	White+300 Black
92	Y.	+ 22	B.B.V.	+246	B.V.	= 82	White+278 Black
62	Y.G.	+ 38	V.	+260	V.R.V.	= 40	White+320 Black
61	G.	+285	V.R.V.	+ 14	R.V.	= 32	White+328 Black
93	B.G.	+267	R.V.			= 50	White+310 Black
262	G.B.	+ 98	O.Y.O.			= 98	White+262 Black
212	B.	+ 76	Y.	+ 72	Y.Y.G.	=122	White+238 Black
215	V.	+105	Y.Y.G.	+ 40	Y.G.	=100	White+260 Black
120	V.R.	+ 14	G.Y.G.	+226	G.	= 62	White+298 Black

TABLE XIII.

Prang.		*Milton-Bradley*		*Complementary.*		*Intensity.*	
155	R.	+191	B.G.	+ 14	G.B.	=114	White+246 Black
130	R.R.O.	+192	B.G.	+ 38	G.B.	= 92	White+268 Black
115	R.O.	+199	B.G.	+ 46	G.B.	= 85	White+275 Black
104	O.R.O.	+200	B.G.	+ 56	G.B.	=117	White+243 Black
100	O.	+171	B.G.	+ 80	G.B.	=120	White+240 Black
85	O.Y.O.	+145	B.G.	+130	G.B.	=124	White+236 Black
115	Y.O.	+ 99	B.G.	+146	G.B.	=125	White+235 Black
120	Y.Y.O.	+ 10	B.G.	+230	G.B.	=131	White+229 Black
145	Y.	+ 52	G.B.	+163	B.	=140	White+220 Black
130	Y.Y.G.	+230	V.			=116	White+244 Black
150	Y.G.	+169	R.V.	+ 41	V.R.	=101	White+259 Black
170	G.Y.G.	+ 34	R.V.	+156	V.R.	= 93	White+267 Black
180	G.	+180	V.R.			= 65	White+295 Black
235	G.B.G.	+ 44	V.R.	+ 81	R.	= 38	White+322 Black
312	B.G.	+ 12	O.	+ 36	Y.O.	= 51	White+309 Black
260	B.B.G.	+ 62	O.Y.	+ 38	Y.	= 95	White+265 Black
201	B.	+ 84	Y.	+ 75	G.Y.	=134	White+226 Black
210	B.B.V.	+ 61	Y.	+ 89	G.Y.	=116	White+244 Black
263	B.V.	+ 37	Y.	+ 60	G.Y.	= 90	White+270 Black
279	V.B.V.	+ 10	Y	+ 71	G.Y.	= 64	White+296 Black
260	V.	+ 80	G.Y.	+ 20	Y.G.	= 75	White+285 Black
298	V.R.V.	+ 42	G.	+ 20	B.G.	= 33	White+327 Black
261	R.V.	+ 10	G.	+ 89	B.G.	= 62	White+298 Black
234	R.R.V.	+126	B.G.			= 55	White+305 Black

TABLE XIV.

Prang.		Hering	Complementary.				Intensity.	
156	R.	+142	B.G.	+ 62	G.B.	= 92	White+268	Black
136	R.R.O.	+126	B.G.	+ 98	G.B.	= 78	White+282	Black
126	R.O.	+ 92	B.G.	+142	G.B.	= 90	White+270	Black
98	O.R.O.	+ 86	B.G.	+176	G.B.	= 92	White+268	Black
93	O.	+ 50	B.G.	+217	G.B.	= 80	Whitc+280	Black
98	O.Y.O.	+ 19	B.G.	+243	G.B.	=113	White+247	Black
110	Y.O.	+232	G.B.	+ 18	B.	=105	White+255	Black
106	Y.Y.O.	+184	G.B.	+ 70	B.	=110	White+250	Black
121	Y.	+ 87	G.B.	+152	B.	=127	White+233	Black
145	Y.Y.G.	+ 82	B.	+133	V.	=115	White+245	Black
151	Y.G.	+122	V.	+ 87	V.R.	= 85	White+275	Black
199	G.Y.G.	+ 90	V.	+ 71	V.R.	= 72	White+288	Black
240	G.	+ 10	V.	+110	V.R.	= 65	White+295	Black
270	G.B.G.	+ 10	V.R.	+ 80	R. I.	= 60	White+300	Black
301	B.G.	+ 45	O.	+ 14	O.Y.	= 65	White+295	Black
242	B.B.G.	+102	O.Y.	+ 16	Y.	= 87	White+273	Black
205	B.	+ 22	O.Y.	+133	Y.	=139	White+221	Black
227	B.B.V.	+128	Y.	+ 5	Y.G.	=121	White+239	Black
272	B.V.	+ 84	Y.	+ 4	Y.G.	= 95	White+265	Black
290	V.B.V.	+ 58	Y.	+ 12	Y.G.	= 70	White+290	Black
264	V.	+ 60	Y.	+ 36	Y.G.	= 90	White+270	Black
300	V.R.V.	+ 20	Y.G.	+ 40	G.	= 40	White+320	Black
258	R.V.	+ 90	B.G.	+ 12	G.B.	= 70	White+290	Black
240	R.R.V.	+ 75	B.G.	+ 45	G.B.	= 58	White+302	Black

It will at once be noticed that these systems of pigment papers have a striking resemblance, and that the characteristics of the figures showing the inter-relations are very similar to those of the diagrams showing the complementaries of each system within itself. The grouping of the complementaries about three points, which are similarly located, is again observed. In the case of the Hering papers, which are fewer in number, the distribution is more noticeable. In the Milton-Bradley system the complementary colours are mainly found between (1) yellow and yellow-green; (2) green and blue; (3) red-violet and red. The complementaries in the Hering papers are grouped between (1) yellow and yellow-green; (2) blue-green and blue; (3) violet and red-violet.

As will be observed, these results furnish the basis for a very definite comparison of the three systems. Thus, we see that the complementary relation of the red in the Milton-Bradley is 136½ blue-green plus 21½ green-blue in the same system; while for the same red the complementary in the Hering is 106½ blue-green plus 69 g.een-blue. Thus it follows that 136½ blue-green plus 21½ green-blue in the Milton-Bradley colours marks the same quality as 106½ blue-green plus 69 green-blue in the Hering papers. The light intensity of the Milton-Bradley complementaries is represented by 278½ black plus 81½ white, as compared with 313 black plus 47 white, which is the intensity of same red with its complementary papers. It follows from this comparison that it is possible to place the colour-qualities of any two of the systems in their approximate relations in the third colour-circle; and then, by rejection of poor or unnecessary colours, we may obtain a very much improved system of pigment papers.

In Table XV we give the complementary relations of a number of frequently used water-colours. The experiments in this instance were carried on by Messrs. D. S. Dix and A. H. Sovereign. Considerable difficulty was experienced in the making of the coloured discs. To get homogeneity of surface and equal saturation, some of the very transparent colours of red and violet had to be mixed with white; while with others (e. g., indigo), the fluorescence was very disturbing. Otherwise the method of experiment was the same as above.

The graphical representation of the complementary relations of these pigment colours (Figure 15) shows great similarity with those of the Milton-Bradley and Prang systems. In these water-colours, also, the complementaries fall for all the colours from red to yellow into a comparatively small region of the colour circle (e. g., the qualities between cobalt-green and cobalt-blue). As revealed by the following Table (XVI), which shows the results of experiments by Mr. M. H. Jackson for all the brown colours, the complementaries of all these can be found between cobalt-green and cobalt-blue. This, of course, does not exclude that a complementary may be constructed consisting of other blue colours, further apart than the two mentioned above.

TABLE XV.

168 Carmine	+ 178 Cobalt Green	+ 14 Emerald Green	= 102 White	+ 258 Black
173 Dragon's Blood	+ 122 Cobalt Green	+ 65 Cerulean Blue	= 123 White	+ 237 Black
232 Indian Red	+ 71 Cobalt Green	+ 57 Cerulean Blue	= 81 White	+ 279 Black
192 Scarlet Vermilion	+ 82 Cobalt Green	+ 86 Cerulean Blue	= 90 White	+ 270 Black
146 Venetian Red	+ 92 Cobalt Green	+ 122 Cerulean Blue	= 111 White	+ 249 Black
126 Chrome Orange	+ 92 Cobalt Green	+ 142 Cerulean Blue	= 123 White	+ 237 Black
139 Cadmium Yellow Pale	+ 188 Cerulean Blue	+ 33 Cobalt Blue	= 128 White	+ 232 Black
152 Gamboge	+ 156 Cerulean Blue	+ 52 Cobalt Blue	= 185 White	+ 175 Black
145 Yellow Lake	+ 51 Cerulean Blue	+ 164 Cobalt Blue	= 177 White	+ 183 Black
123 Chrome Lemon	+ 237 Smalt		= 236 White	+ 124 Black
181 Alizarin Green	+ 35 Purple Lake	+ 144 Mauve	= 102 White	+ 258 Black
205 Sap Green	+ 97 Mauve	+ 58 Purple Lake	= 90 White	+ 270 Black
114 Emerald Green	+ 6 Mauve	+ 240 Purple Lake	= 84 White	+ 276 Black
178 Cobalt Green	+ 157 Carmine	+ 25 Dragon's Blood	= 118 White	+ 242 Black
217 Cerulean Blue	+ 94 Chrome Orange	+ 49 Cadmium Yellow Pale	= 156 White	+ 204 Black
205 Cobalt Blue	+ 144 Yellow Lake	+ 11 Chrome Lemon	= 157 White	+ 20[illegible] Black
245 Prussian Blue	+ 35 Chrome Lemon	+ 80 Yellow Lake	= 114 White	+ 246 Black
242 Smalt	+ 118 Chrome Lemon		= 218 White	+ 142 Black
191 French Blue	+ 151 Chrome Lemon	+ 18 Alizarin Green	= 175 White	+ 185 Black
188 Mauve	+ 29 Chrome Lemon	+ 143 Alizarin Green	= 120 White	+ 240 Black
215 Purple Lake	+ 118 Emerald Green	+ 27 Cobalt Green	= 109 White	+ 251 Black
171 Madder Lake	+ 164 Emerald Green	+ 25 Cerulean Blue	= 113 White	+ 247 Black
304 Indigo	+ 56 Yellow Lake		= 84 White	+ 276 Black
250 Oxide of Chromium	+ 77 Purple Lake	+ 33 Mauve	= 87 White	+ 273 Black
135 Orange Vermilion	+ 153 Emerald Green	+ 72 Cerulean Blue	= 134 White	+ 226 Black

TABLE XVI.

207 Brown Madder	+ 99 Cobalt Green	+ 54 Cerulean Blue	= 103 White	+ 257 Black
180 Burnt Sienna	+ 107 Cobalt Green	+ 73 Cerulean Blue	= 92 White	+ 268 Black
257 Burnt Umber	+ 46 Cobalt Green	+ 57 Cerulean Blue	= 77 White	+ 283 Black
276 Van Dyke Brown	+ 30 Cobalt Green	+ 54 Cerulean Blue	= 62 White	+ 298 Black.
235 Raw Umber	+ 40 Cobalt Green	+ 85 Cerulean Blue	= 85 White	+ 275 Black
177 Brown Ochre	+ 58 Cobalt Green	+ 125 Cerulean Blue	= 103 White	+ 257 Black
280 Warm Sepia	+ 23 Cobalt Green	+ 57 Cerulean Blue	= 62 White	+ 298 Black
315 Roman Sepia	+ 10 Cobalt Green	+ 35 Cerulean Blue	= 33 White	+ 327 Black
152 Yellow Ochre	+ 26 Cobalt Green	+ 182 Cerulean Blue	= 128 White	+ 232 Black
310 Sepia	+ 16 Cobalt Green	+ 34 Cerulean Blue	= 35 White	+ 325 Black
155 Raw Sienna	+ 15 Cobalt Green	+ 190 Cerulean Blue	= 125 White	+ 235 Black
275 Bistre	+ 85 Cerulean Blue		= 95 White	+ 265 Black
216 Brown Pink	+ 123 Cerulean Blue	+ 21 Cobalt Blue	= 112 White	+ 248 Black
178 Yellow Carminet	+ 133 Cerulean Blue	+ 49 Cobalt Blue	= 124 White	+ 236 Black

It is well known that the mixture of the painted colours on rotating discs cannot be expected to have the same results as the mixture of the pigments in the liquid state. The mixture of two perfectly transparent liquids is, from the standpoint of colour, no mixture at all, for it is not an addition, but a subtraction. Each of the components absorbs certain regions of the spectrum, and what one component has absorbed cannot be transmitted by the other. That is the reason why mixed transparent coloured liquids are always darker than either of the components. If the two liquids are complementary, the resultant may be colourless, yet not white, but grey. And if the components are very fully saturated, it may even be black. In fact, the best lampblack is no quite so dark as the black which the painters produce from carmine, indigo, and some green colour.

The perfectly opaque colours, on the other hand, behave, when mixed, like the mixture of coloured powders. If mixed as liquids they show the same result as when mixed as powders or on the rotating discs, with this difference only, that there is a somewhat greater saturation in the case of the suspension in the liquid. There are very few approximately perfectly transparent colours. The water-colours used by painters are, in most cases, something between an opaque and a transparent colour, some of them, like carmine, the lakes, Prussian blue, sap-green, and gamboge being rather transparent; others, like vermilion, the chromes, red lead, etc., being more or less completely opaque; whilst the qualities of all the rest are between these extremes.

Our experiments in this instance were directed to the mixture of the water-colours in a liquid state, so as to produce colourless mixtures in transmitted light. To a glass of water, sufficient of the pigment was added to give a high degree of saturation; then we sought to find another pigment, similarly diluted, which would give colourless light when combined with this. In only one case did we find the mixture of two to have this result, viz., with alizarin-green and smalt. In all other cases a third and neighbouring quality was necessary, as was required usually with the rotating discs. The results are given in Table XVII. The great majority of the mixtures were semi-transparent, those least transparent being numbered 14 and 15 in the Table; while the mixtures indicated by numbers 8, 10, 16 and 20 were the most highly transparent. In Table XVIII w give the results of similar experiments with highly transparen coloured pigments, known under the name of Verdin's Magi Photo Tints. In the mixture with the pink, the result wa unsatisfactory, owing to the fluorescence, but in all the othe cases almost perfectly transparent colourless mixtures wer obtained.

TABLE XVII.

Water Colours—Liquid Mixture.

Approximately colourless mixtures (in transmitted light) can be pr duced by:

(1) Carmine	+ Cobalt Green	+ Emerald Green
(2) Dragon's Blood	+ Cobalt Green	+ Cerulean Blue
(3) Indian Red	+ Emerald Green	+ Cobalt Green
(4) Venetian Red	+ Cobalt Green	+ Cerulean Blue
(5) Scarlet Vermilion	+ Cobalt Green	+ Cerulean Blue
(6) Chrome Orange	+ Cobalt Green	+ Cerulean Blue
(7) Cadmium Yellow Pale	+ Cobalt Green	+ Cerulean Blue
(8) Gamboge	+ Cerulean Blue	+ Cobalt Blue
(9) Yellow Lake	+ Cerulean Blue	+ Cobalt Blue
(10) Chrome Lemon	+ Smalt	
(11) Alizarin Green	+ Purple Lake	+ Mauve
(12) Sap Green	+ Mauve	+ Purple Lake
(13) Emerald Green	+ Mauve	+ Purple Lake
(14) Cobalt Green	+ Carmine	+ Dragon's Blood
(15) Cerulean Blue	+ Chrome Orange	+ Cadmium Yellow P
(16) Cobalt Blue	+ Yellow Lake	+ Chrome Lemon
(17) Prussian Blue	+ Chrome Lemon	+ Yellow Lake
(18) Smalt	+ Chrome Lemon	
(19) French Blue	+ Chrome Lemon	+ Alizarin Green
(20) Mauve	+ Chrome Lemon	+ Alizarin Green
(21) Purple Lake	+ Emerald Green	+ Cobalt Green
(22) Madder Lake	+ Emerald Green	+ Cerulean Blue
(23) Indigo	+ Chrome Lemon	+ Yellow Lake
(24) Oxide of Chromium	+ Dragon's Blood	+ Carmine
(25) Orange Vermilion	+ Emerald Green	+ Cerulean Blue

TABLE XVIII.

Verdin's Magic Photo Tints—Perfectly transparent Colours—Liquid Mixture.

Colourless mixtures were produced by:

(1)	Brown	+ Green	+ very little Purple
(2)	Yellow	+ Green	+ little Magenta
(3)	Magenta	+ Green	+ much Yellow
(4)	Purple	+ Yellow	+ little Green
(5)	Blue	+ Yellow	+ little Magenta
(6)	Green	+ much Yellow	+ Magenta
	Green	+ Brown	+ little Magenta
(7)	Green	+ much Flesh Colour	
(8)	Pink	+ much Green	+ much Yellow

MILTON-BRADLEY SYSTEM.

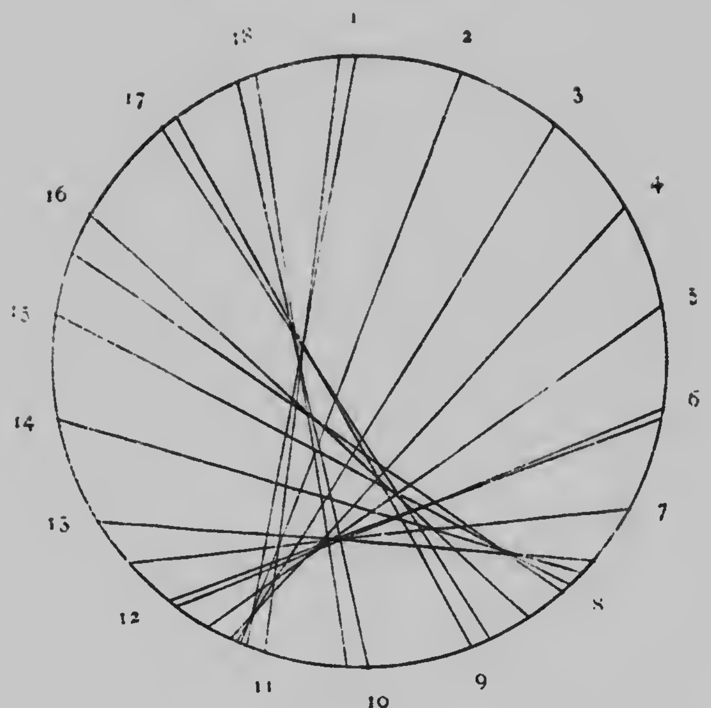

FIG. 2.

1. Red.
2. Orange Red.
3. Red Orange.
4. Orange.
5. Yellow Orange.
6. Orange Yellow.
7. Yellow.
8. Green Yellow.
9. Yellow Green.
10. Green.
11. Blue Green.
12. Green Blue.
13. Blue.
14. Violet Blue.
15. Blue Violet.
16. Violet.
17. Red Violet.
18. Violet Red.

MILTON-BRADLEY SYSTEM: TINTS (No. 2).

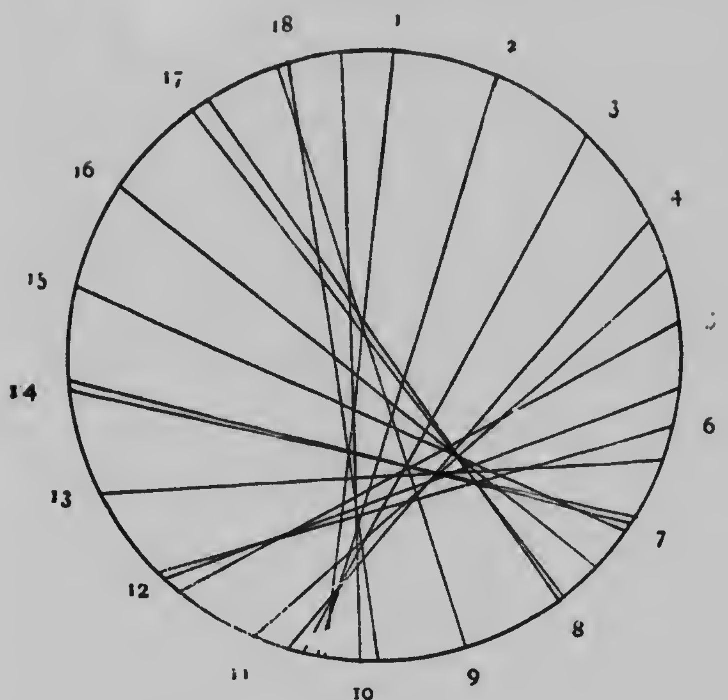

FIG. 3.

1. Red.
2. Orange Red.
3. Red Orange.
4. Orange.
5. Yellow Orange.
6. Orange Yellow.
7. Yellow.
8. Green Yellow.
9. Yellow Green.
10. Green.
11. Blue Green.
12. Green Blue.
13. Blue.
14. Violet Blue.
15. Blue Violet.
16. Violet.
17. Red Violet.
18. Violet Red.

MILTON-BRADLEY SYSTEM: SHADES (No. 2).

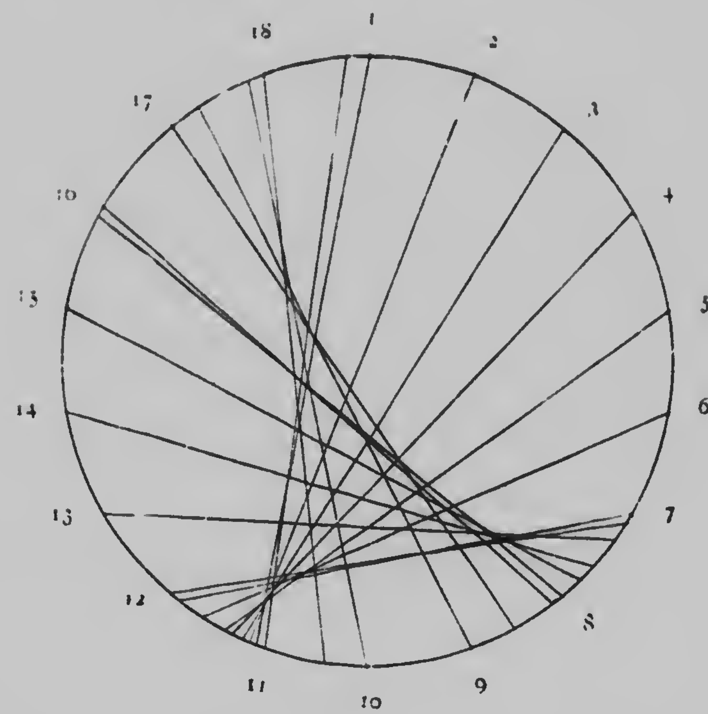

FIG. 4.

1. Red.
2. Orange Red.
3. Red Orange.
4. Orange.
5. Yellow Orange.
6. Orange Yellow.
7. Yellow.
8. Green Yellow.
9. Yellow Green.
10. Green.
11. Blue Green.
12. Green Blue.
13. Blue.
14. Violet Blue.
15. Blue Violet.
16. Violet.
17. Red Violet.
18. Violet Red.

HERING SYSTEM.

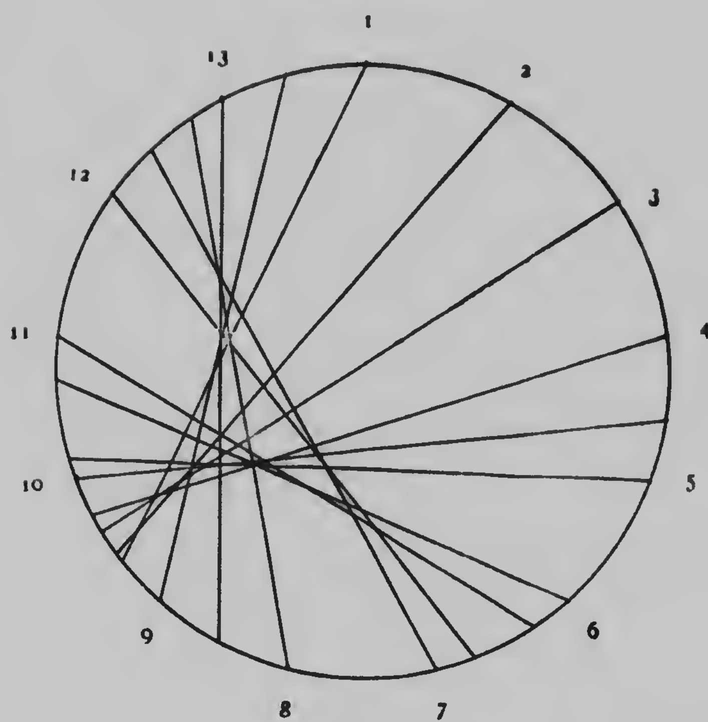

FIG. 5.

1. Red I.
2. Red II.
3. Orange Red.
4. Orange.
5. Orange Yellow.
6. Yellow.
7. Yellow Green.
8. Green.
9. Blue Green.
10. Green Blue.
11. Blue.
12. Violet.
13. Violet Red.

PRANG SYSTEM.

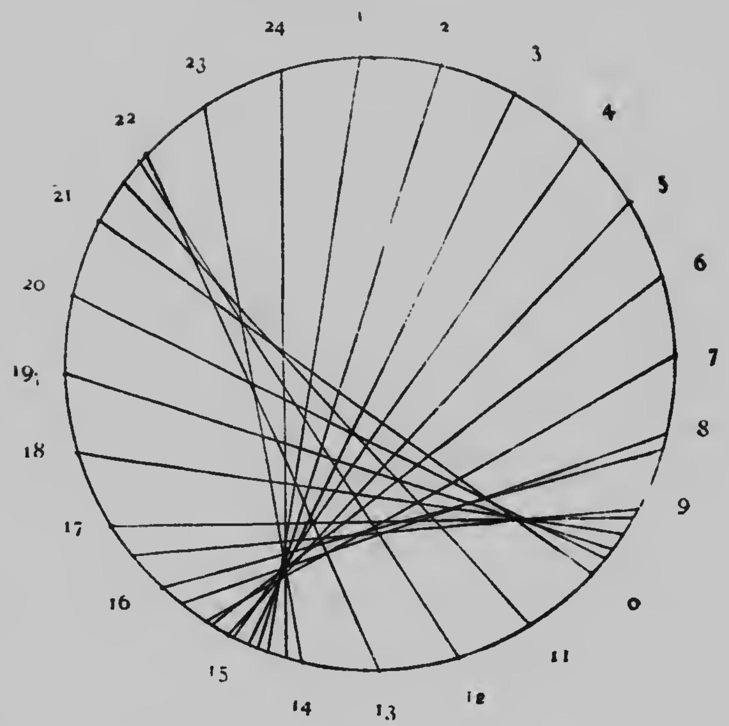

FIG. 6.

1. Red.
2. Red Red Orange.
3. Red Orange.
4. Orange Red Orange.
5. Orange.
6. Orange Yellow Orange.
7. Yellow Orange.
8. Yellow Yellow Orange.
9. Yellow.
10. Yellow Yellow Green.
11. Yellow Green.
12. Green Yellow Green.
13. Green.
14. Green Blue Green.
15. Blue Green.
16. Blue Blue Green.
17. Blue.
18. Blue Blue Violet.
19. Blue Violet.
20. Violet Blue Violet.
21. Violet.
22. Violet Red Violet.
23. Red Violet.
24. Red Red Violet.

PRANG SYSTEM, REPRINTED FROM MISS BAKER'S ARTICLE.

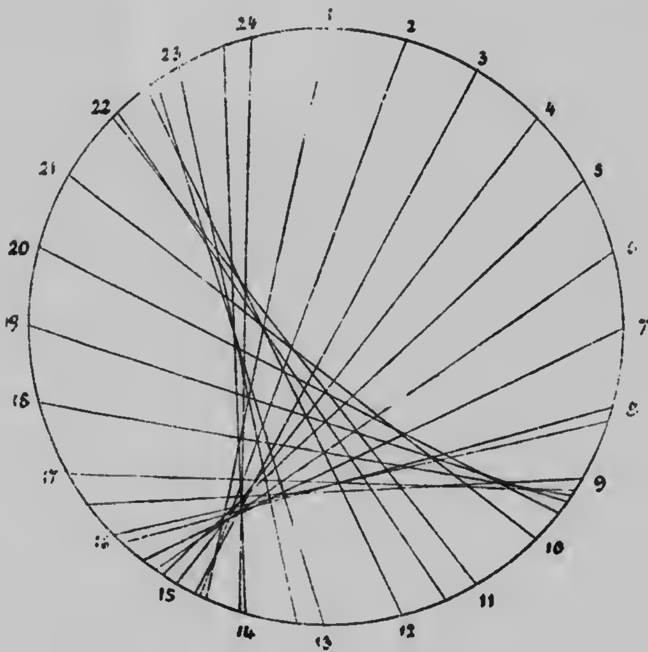

FIG. 7.

SPECTRALLY PURE COLOURS.

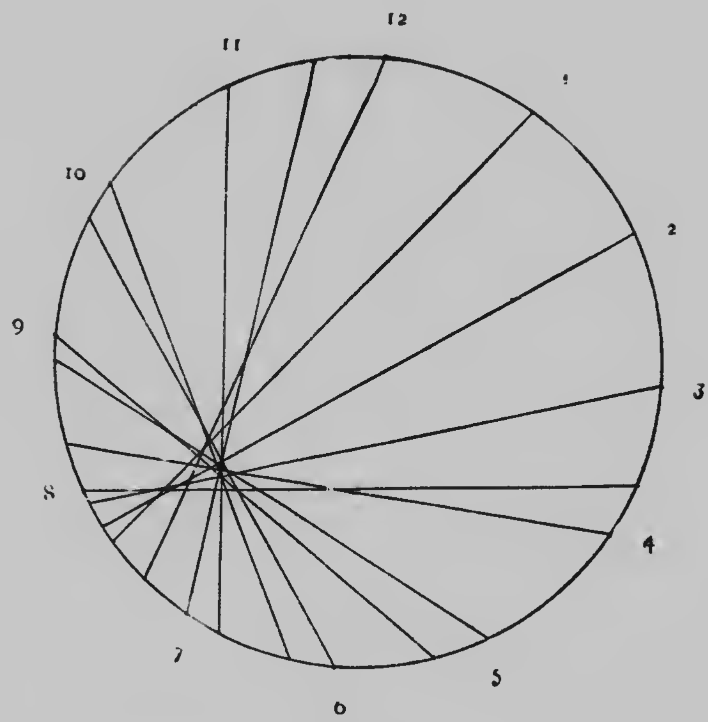

FIG. 8.

1. Red.
2. Orange Red.
3. Orange.
4. Orange Yellow.
5. Yellow.
5. Yellow Green..
7. Green.
8. Green Blue.
9. Blue.
10. Violet.
11. Violet Purple.
12. Purple.

MILTON-BRADLEY—HERING.

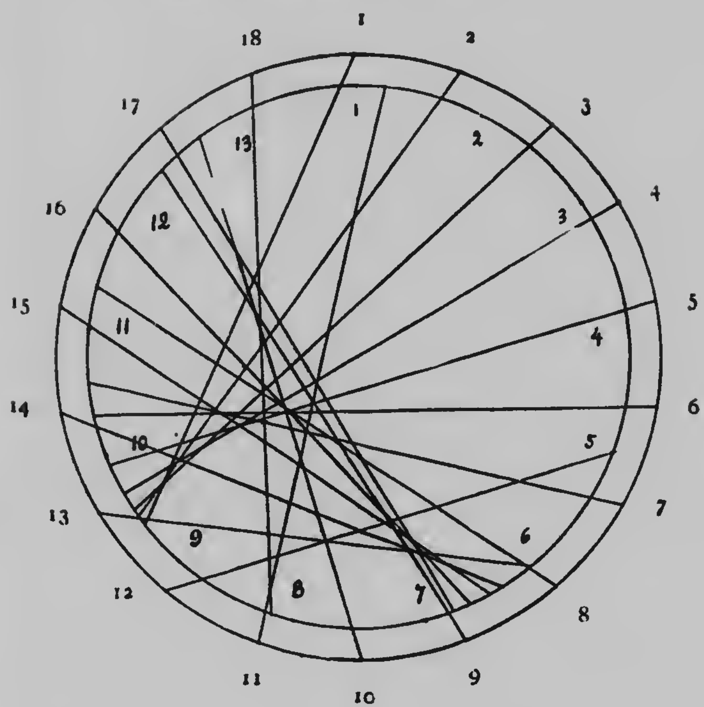

FIG. 9.

Milton-Bradley.

1. Red.
2. Orange Red.
3. Red Orange.
4. Orange.
5. Yellow Orange.
6. Orange Yellow.
7. Yellow.
8. Green Yellow.
9. Yellow Green.
10. Green.
11. Blue Green.
12. Green Blue.
13. Blue.
14. Violet Blue.
15. Blue Violet.
16. Violet.
17. Red Violet.
18. Violet Red.

Hering.

1. Red I.
2. Red II.
3. Orange Red.
4. Orange.
5. Orange Yellow.
6. Yellow.
7. Yellow Green.
8. Green.
9. Blue Green.
10. Green Blue.
11. Blue.
12. Violet.
13. Violet Red.

MILTON-BRADLEY—PRANG.

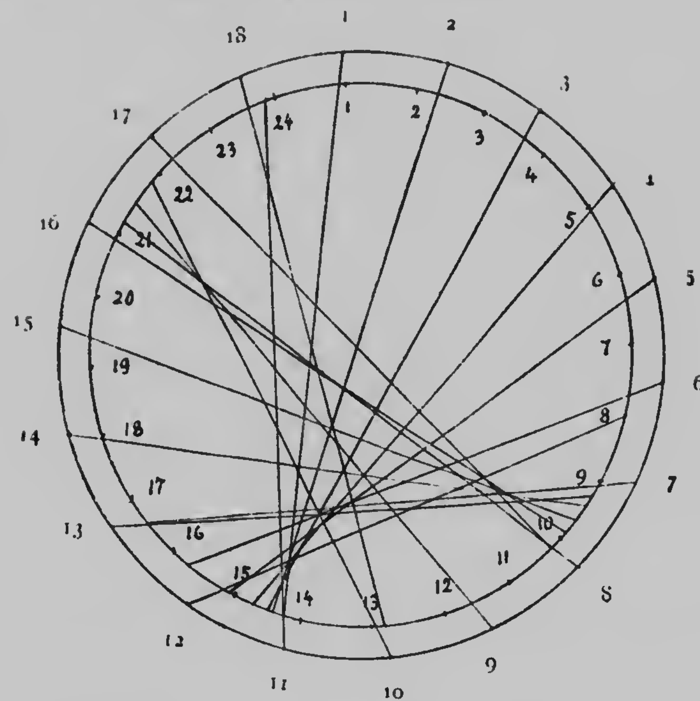

FIG. 10.

Milton-Bradley.

1. Red.
2. Orange Red.
3. Red Orange.
4. Orange.
5. Yellow Orange.
6. Orange Yellow.
7. Yellow.
8. Green Yellow.
9. Yellow Green.
10. Green.
11. Blue Green.
12. Green Blue.
13. Blue.
14. Violet Blue.
15. Blue Violet.
16. Violet.
17. Red Violet.
18. Violet Red.

Prang.

1. Red.
2. Red Red Orange.
3. Red Orange.
4. Orange Red Orange.
5. Orange.
6. Orange Yellow Orange.
7. Yellow Orange.
8. Yellow Yellow Orange.
9. Yellow.
10. Yellow Yellow Green.
11. Yellow Green.
12. Green Yellow Green.
13. Green.
14. Green Blue Green.
15. Blue Green.
16. Blue Blue Green.
17. Blue.
18. Blue Blue Violet.
19. Blue Violet.
20. Violet Blue Violet.
21. Violet.
22. Violet Red Violet.
23. Red Violet.
24. Red Red Violet.

HERING—MILTON-BRADLEY.

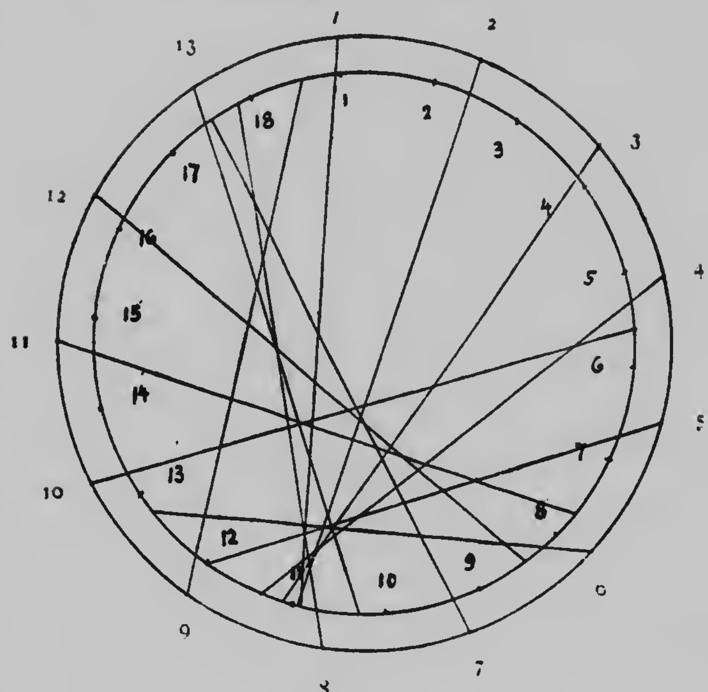

FIG. 11.

Hering.

1. Red I.
2. Red II.
3. Orange Red.
4. Orange.
5. Orange Yellow.
6. Yellow.
7. Yellow Green.
8. Green.
9. Blue Green.
10. Green Blue.
11. Blue.
12. Violet.
13. Violet Red.

Milton-Bradley.

1. Red.
2. Orange Red.
3. Red Orange.
4. Orange.
5. Yellow Orange.
6. Orange Yellow.
7. Yellow.
8. Green Yellow.
9. Yellow Green.
10. Green.
11. Blue Green.
12. Green Blue.
13. Blue.
14. Violet Blue.
15. Blue Violet.
16. Violet.
17. Red Violet.
18. Violet Red.

HERING—PRANG.

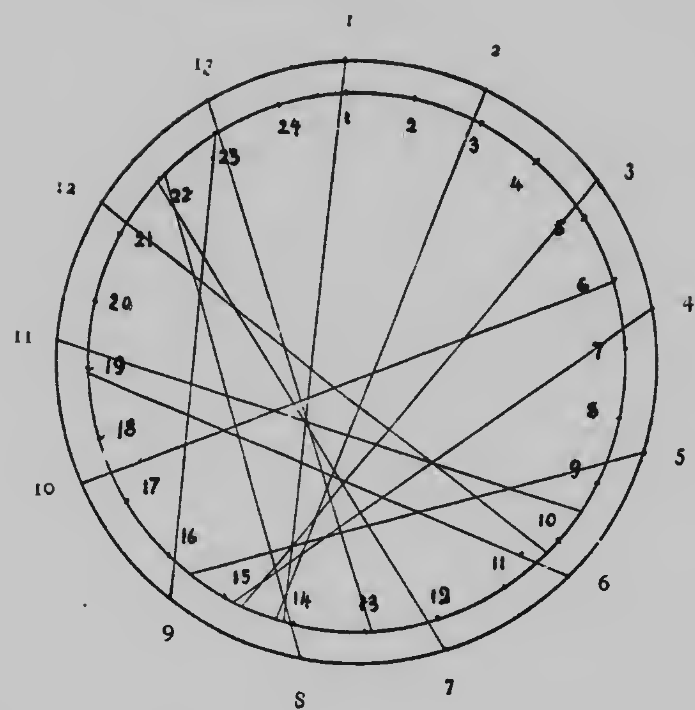

FIG. 12.

Hering.

1. Red I.
2. Red II.
3. Orange Red.
4. Orange.
5. Orange Yellow.
6. Yellow.
7. Yellow Green.
8. Green.
9. Blue Green.
10. Green Blue.
11. Blue.
12. Violet.
13. Violet Red.

Prang.

1. Red.
2. Red Red Orange.
3. Red Orange.
4. Orange Red Orange.
5. Orange.
6. Orange Yellow Orange.
7. Yellow Orange.
8. Yellow Yellow Orange.
9. Yellow.
10. Yellow Yellow Green.
11. Yellow Green.
12. Green Yellow Green.
13. Green.
14. Green Blue Green.
15. Blue Green.
16. Blue Blue Green.
17. Blue.
18. Blue Blue Violet.
19. Blue Violet.
20. Violet Blue Violet.
21. Violet.
22. Violet Red Violet.
23. Red Violet.
24. Red Red Violet.

PRANG—MILTON-BRADLEY.

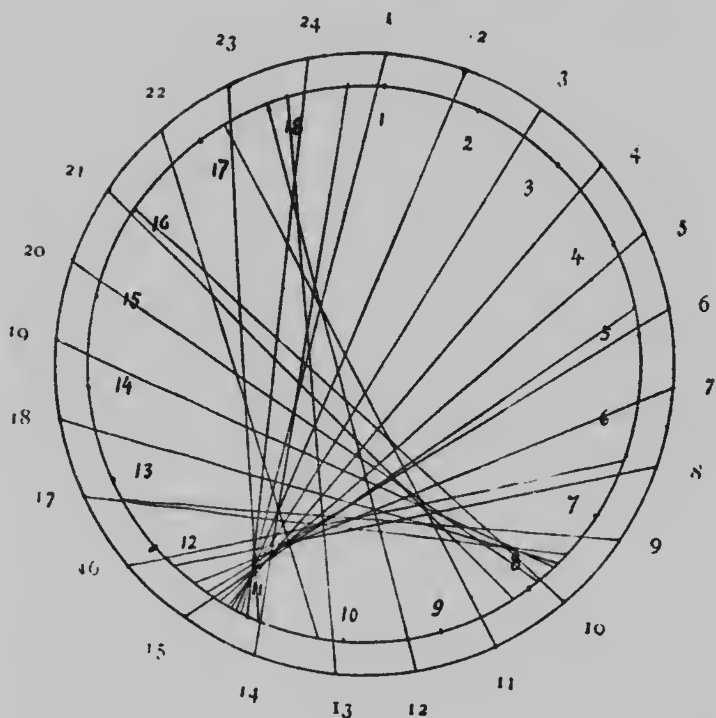

FIG. 13.

Prang.

1. Red.
2. Red Red Orange.
3. Red Orange.
4. Orange Red Orange.
5. Orange.
6. Orange Yellow Orange.
7. Yellow Orange.
8. Yellow Yellow Orange.
9. Yellow.
10. Yellow Yellow Green.
11. Yellow Green.
12. Green Yellow Green.
13. Green.
14. Green Blue Green.
15. Blue Green.
16. Blue Blue Green.
17. Blue.
18. Blue Blue Violet.
19. Blue Violet.
20. Violet Blue Violet.
21. Violet.
22. Violet Red Violet.
23. Red Violet.
24. Red Red Violet.

Milton-Bradley.

1. Red.
2. Orange Red.
3. Red Orange.
4. Orange.
5. Yellow Orange.
6. Orange Yellow.
7. Yellow.
8. Green Yellow.
9. Yellow Green.
10. Green.
11. Blue Green.
12. Green Blue.
13. Blue.
14. Violet Blue.
15. Blue Violet.
16. Violet.
17. Red Violet.
18. Violet Red.

PRANG—HERING.

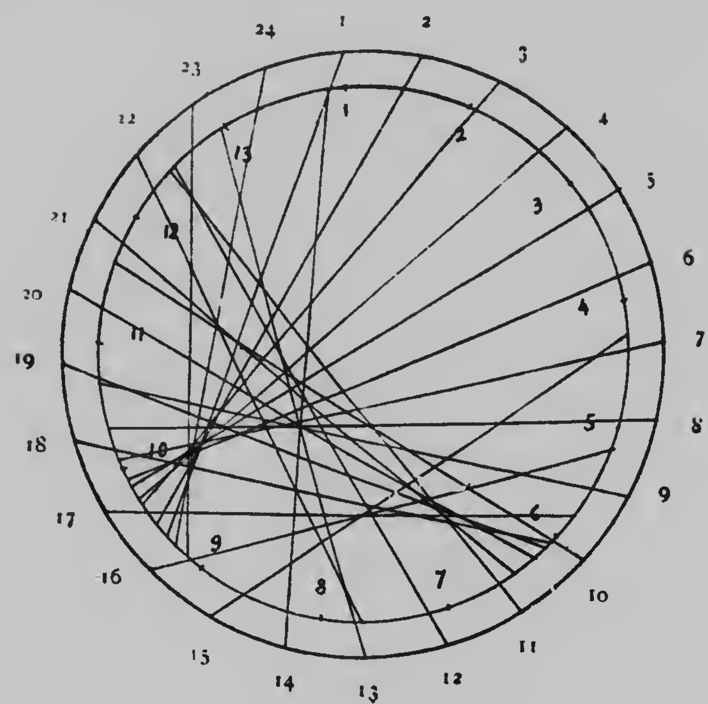

FIG. 14.

Prang.

1. Red.
2. Red Red Orange.
3. Red Orange.
4. Orange Red Orange.
5. Orange.
6. Orange Yellow Orange.
7. Yellow Orange.
8. Yellow Yellow Orange.
9. Yellow.
10. Yellow Yellow Green.
11. Yellow Green.
12. Green Yellow Green.
13. Green.
14. Green Blue Green.
15. Blue Green.
16. Blue Blue Green.
17. Blue.
18. Blue Blue Violet.
19. Blue Violet.
20. Violet Blue Violet.
21. Violet.
22. Violet Red Violet.
23. Red Violet.
24. Red Red Violet.

Hering.

1. Red I.
2. Red I'
3. Orang Red.
4. Orange.
5. Orange Yellow.
6. Yellow.
7. Yellow Green.
8. Green.
9. Blue Green.
10. Green Blue.
11. Blue.
12. Violet.
13. Violet Red.

WATER COLOURS.

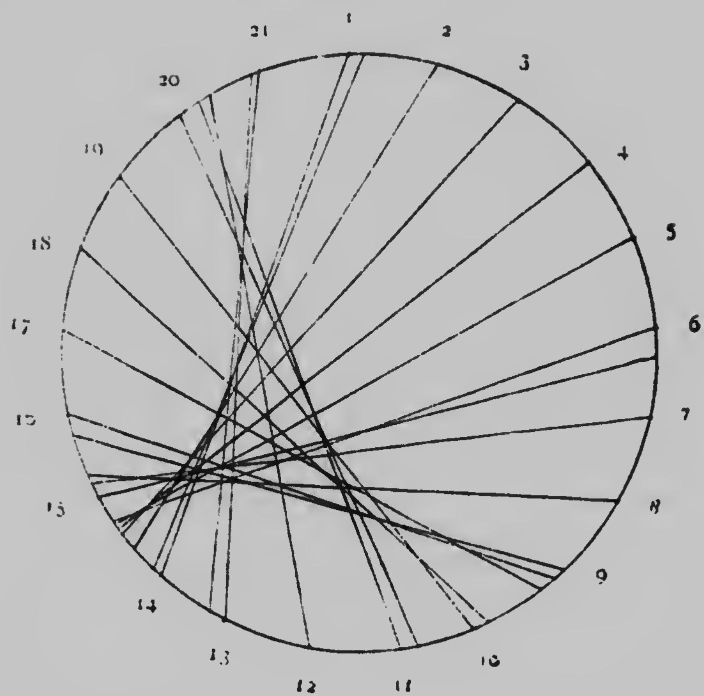

FIG. 15.

1. Carmine.
2. Dragon's Blood.
3. Indian Red.
4. Scarlet Vermilion.
5. Venetian Red.
6. Chrome Orange.
7. Cadmium Yellow Pale.
8. Gamboge.
9. Yellow Lake.
10. Chrome Lemon.
11. Alizarin Green.
12. Sap Green.
13. Emerald Green.
14. Cobalt Green.
15. Cerulean Blue.
16. Cobalt Blue.
17. Prussian Blue.
18. Smalt.
19. French Blue.
20. Mauve.
21. Purple Lake.

III.

COMPLEMENTARY RELATIONS AS AFFECTED BY CONTRAST

Milton-Bradley Papers—Three Sets of Backgrounds

We now come to the consideration of the problem which complementarism affords when viewed in its relation to colour contrast. From the ascertained laws of light and colour-contrast we know that a grey pattern traced on a red ground will not appear pure grey, but tinged with a colour complementary to that of the ground. If we substitute for the red any other bright colour, it will be found that the grey is more or less tinged with the complementary colour-tone. As black is really a dark grey we should expect to find it also assuming to some extent a colour complementary to that of the ground; and this is the case, though the effect is not quite so marked. In these cases the effect is more striking if the colour-quality be very bright or of full saturation. It is also increased if the grey is of comparatively small area and completely surrounded by the colour. Now if we substitute a colour for the grey, then both coloured surfaces will be modified by the mutual contrast influence. The following Table shows the influence of contrast, as determined through experiments performed by Hurst.* These results agree substantially with those of Rood†:

	Colour Pairs	*Modification by Contrast*
(1)	Red	inclines to Violet
	Orange	" Yellow
(2)	Red	" Violet
	Yellow	" Greenish-yellow
(3)	Red	becomes more brilliant
	Green	" "
(4)	Red	inclines to Orange
	Blue	" Green
(5)	Red	" Yellow
	Cyan-blue	" Blue-green

* Hurst, *Colour*, p. 107.

† *Text-Book of Colour or Modern Chromatics*, p. 245.

	Colour Pairs	Modification by Contrast
(6)	Red	inclines to Orange
	Violet	" Blue
(7)	Orange	" Red-orange
	Yellow	" Greenish-yellow
(8)	Orange	" Red-orange
	Green	" Bluish-green
(9)	Orange	becomes more brilliant
	Cyan-blue	" "
(10)	Orange	inclines to Yellow
	Violet	" Bluish
(11)	Yellow	" bright Orange
	Green	" Blue
(12)	Yellow	" Orange-yellow
	Cyan-blue	" bright Blue
(13)	Yellow	becomes more brilliant
	Bright Blue	" "
(14)	Green	inclines to Yellow
	Blue	" Violet
(15)	Green	" Yellow-green
	Violet	" Reddish
(16)	Greenish-yellow	becomes more brilliant
	Violet	" "
(17)	Blue	inclines to Greenish
	Violet	" Reddish

It will be seen from the above Table that the alterations produced by contrast are orderly. When any two colour-qualities of the chromatic circle are contrasted, the effect produced is apparently to move them farther apart. In the case, for example, of orange and yellow, the orange appears to be a quality more nearly red; the yellow tends to greenish. Colours which are complementary are already as far apart in the chromatic circle as possible, hence they are not changed in quality, but merely appear more brilliant and saturated. The changes are greatest with the colours which are situated nearest to each other in the chromatic circle, and much less with those at a distance. Thus red and yellow are much changed by contrast, the red becoming purplish, the yellow greenish; while red with cyan-blue or blue is much less affected in the matter of displacement or change of hue. On the other hand, the colours which are very distant from each other in the chromatic circle, while suffering but slight changes in hue, are made to appear more brilliant and saturated.

Colours which are identical are affected by contrast in exactly the opposite way from those which are complementary —that is, they are made to appear duller and less saturated. If the two colours are identical except in the matter of saturation, it will also be found that the one which is more saturated will gain in colour, while its less saturated rival will lose. If the less saturated is of comparatively little saturation, it may even appear uncoloured altogether. A light pink, when surrounded by the same quality in very high saturation (i.e., the crimson-red), may appear white. Similarly, a dark blue of little saturation, when surrounded by a fully saturated blue, may appear completely black. But it is not a necessary conclusion that the surrounded surface is always the loser. In an experiment with coloured shadows, which Professor Kirschmann uses in the class-room to demonstrate contrast phenomena, it occurs very often that the contrast colour is seen with great saturation, whilst the physical cause (i.e., the inducing colour, which is of little saturation and spread over a great surface) is not noticed at all.

To ascertain whether the same principles of light and colour contrast would obtain wh[illegible] coloured surfaces were used as backgrounds, experiments were performed with the eighteen Milton-Bradley colours under the conditions previously named, except that instead of the dull, black background, coloured backgrounds of red, orange, yellow, green, blue, and violet from the same system were used in successive experiments with the coloured discs. Then the experiments were repeated, the original dull, black background being used for the coloured discs and the six coloured backgrounds successively behind the black and the white discs. A third set of equations was then found, when large coloured backgrounds for the two Marbe's apparatus were used. The smaller backgrounds were 11 inches by 13 inches, while those for both sets of discs measured 23 inches by 13 inches. The experiments were performed by Mr. G. M. Dix and

Miss N. O. Markland; and the following Tables are statements of equations under these conditions. From XX to XXV the Tables state the results where coloured backgrounds were used with the coloured discs; while XXVI and XXXI are the Tables giving results when coloured backgrounds were used with the uncoloured discs. Finally, Tables XXXII to XXXVII give the equations where the large coloured backgrounds were used.

TABLE XIX.

Using the ordinary dull black background.

218½	R.	+ 120	B.G.	+ 21½	G.B.	= 70	White + 200	Black
134	O.R.	+ 192½	B.G.	+ 33½	G.B.	= 87	White + 273	Black
114	R.O.	+ 198½	B.G.	+ 47½	G.B.	= 107	White + 253	Black
100	O.	+ 175	B.G.	+ 85	G.B.	= 103	White + 257	Black
121	Y.O.	+ 106	B.G.	+ 133	G.B.	= 115	White + 245	Black
128	O.Y.	+ 17	B.G.	+ 215	G.B.	= 140	White + 220	Black
140½	Y.	+ 108	G.B	+ 111½	B.	= 154	White + 206	Black
160	G. Y.	+ 90	B.V.	+ 110	V.	= 137	White + 223	Black
137	Y.G.	+ 175	R.V.	+ 48	V.R.	= 139	[illegible]	Black
142	G.	+ 37	R.V.	+ 181	V.R.	= 103	[illegible]	Black
155½	B.G.	+ 27	V.R.	+ 177½	R.	= 78	White + [illegible]	Black
230	G.B.	+ 126	O.Y.	+ 4	Y.	= 160	White + 200	Black
175½	B.	+ 78	Y.	+ 106½	G.Y.	= 145	White + 215	Black
188½	V.B.	+ 52	Y.	+ 119½	G.Y.	= 125	White + 235	Black
194	B.V.	+ 16	Y.	+ 150	G.Y.	= 152	White + 208	Black
230½	V.	+ 83	G.Y.	+ 46½	Y.G.	= 119	White + 241	Black
227½	R.V.	+ 25	G.Y.	+ 107½	Y.G.	= 115	White + 245	Black
230½	V.R.	+ 105½	G.	+ 24	B.G.	= 80	White + 280	Black

TABLE XX.

Red Background with Coloured Discs.

229½	R.	+ 100	B.G.	+ 21½	G.B.	= 55	White + 305	Black
144	O.R.	+ 182½	B.G.	+ 33½	G.B.	= 99	White + 261	Black
115	R.O.	+ 197½	B.G.	+ 47½	G.B.	= 117	White + 243	Black
105	O.	+ 170	B.G.	+ 85	G.B.	= 76	White + 284	Black
132	Y.O.	+ 95	B.G.	+ 133	G.B.	= 115	White + 245	Black
134	O.Y.	+ 11	B.G.	+ 215	G.B.	= 135	White + 225	Black
142½	Y.	+ 106	G.B.	+ 111½	B.	= 139	White + 221	Black
160	G.Y.	+ 00	B.V.	+ 110	V.	= 137	White + 223	Black
132	Y.G.	+ 180	R.V.	+ 48	V.R.	= 126	White + 234	Black
138	G.	+ 41	[illegible]	+ 181	V.R.	= 90	White + 270	Black
154	B.G.	+ 28½	[illegible]	+ 177½	R.	= 81	White + 279	Black
222	G.B.	+ 134	O.Y.	+ 4	Y.	= 161	White + 199	Black
179	B.	+ 74½	Y.	+ 106½	G.Y.	= 105	White + 255	Black
182½	V.B.	+ 58	Y.	+ 119½	G.Y.	= 135	White + 225	Black
175	B.V.	+ 35	Y.	+ 150	G.Y.	= 152	White + 208	Black
228½	V.	+ 85	G.Y.	+ 46½	Y.G.	= 105	White + 255	Black
227½	R.V.	+ 25	G.Y.	+ 107½	Y.G.	= 145	White + 215	Black
233½	V.R.	+ 105½	G.	+ 21	B.G.	= 80	White + 280	Black

TABLE XXI.

Orange Background with Coloured Discs.

220½	R.	+ 118	B.G.	+ 21½	G.B.	= 70	White + 290	Black
142	O.R.	+ 184½	B.G.	+ 33½	G.B.	= 74	White + 286	Black
115	R.O.	+ 197½	B.G.	+ 47½	G.B.	= 113	White + 247	Black
131	O.	+ 144	B.G.	+ 85	G.B.	= 98	White + 262	Black
123	Y.O.	+ 104	B.G.	+ 133	G.B.	= 180	White + 180	Black
132	O.Y.	+ 13	B.G.	+ 215	G.B.	= 128	White + 232	Black
140	Y.	+ 108½	G.B.	+ 111½	B.	= 151	White + 209	Black
170	G.Y.	+ 100	V.	+ 90	B.V.	= 137	White + 223	Black
140	Y.G.	+ 172	R.V.	+ 48	V.R.	= 129	White + 231	Black
142	G.	+ 37	R.V.	+ 181	V.R.	= 89	White + 271	Black
154½	B.G.	+ 28	V.R.	+ 177½	R.	= 58	White + 302	Black
225	G.B.	+ 131	O.Y.	+ 4	Y.	= 152	White + 208	Black
164½	B.	+ 89	Y.	+ 106½	G.Y.	= 131	White + 229	Black
184½	V.B.	+ 56	Y.	+ 119½	G.Y.	= 124	White + 236	Black
182	B.V.	+ 28	Y.	+ 150	G.Y.	= 121	White + 239	Black
234½	V.	+ 79	G.Y.	+ 46½	Y.G.	= 109	White + 251	Black
225½	R.V.	+ 27	G.Y.	+ 107½	Y.G.	= 136	White + 224	Black
231	V.R.	+ 105½	G.	+ 23½	B.G.	= 90	White + 270	Black

TABLE XXII.

Yellow Background with Coloured Discs.

219½	R.	+119	B.G.	+ 21½	G.B.	= 65	White	+295	Black
135	O.R.	+191½	B.G.	+ 33½	G.B.	= 69	White	+291	Black
110	R.O.	+202½	B.G.	+ 47½	G.B.	= 80	White	+280	Black
119	O.	+156	B.G.	+ 85	G.B.	= 91	White	+269	Black
124	Y.O.	+103	B.G.	+133	G.B.	= 80	White	+280	Black
129	O.Y.	+ 16	B.G.	+215	G.B.	=137	White	+223	Black
158½	Y.	+ 90	G.B.	+111½	B.	=140	White	+220	Black
178	G.Y.	+ 92	V.	+ 90	B.V.	=125	White	+235	Black
142	Y.G.	+170	R.V.	+ 48	V.R.	=118	White	+242	Black
129	G.	+ 50	R.V.	+181	V.R.	= 72	White	+288	Black
150	B.G.	+ 32½	V.R.	+177½	R.	= 58	White	+202	Black
223	G.B.	+133	O.Y.	+ 4	Y.	=132	White	+228	Black
168½	B.	+ 85	Y.	+106½	G.Y.	=110	White	+250	Black
185½	V.B.	+ 55	Y.	+119½	G.Y.	=101	White	+259	Black
164	B.V.	+ 46	Y.	+150	G.Y.	=141	White	+219	Black
227½	V.	+ 86	G.Y.	+ 46½	Y.G.	=118	White	+242	Black
217½	R.V.	+ 35	G.Y.	+107½	Y.G.	=115	White	+245	Black
230	V.R.	+105½	G.	+ 24½	B.G.	= 55	White	+305	Black

TABLE XXIII.

Green Background with Coloured Discs.

216½	R.	+122	B.G.	+ 21½	G.B.	= 76½	White	+283½	Black
122	O.R.	+204½	B.G.	+ 33½	G.B.	= 88	White	+272	Black
103	R.O.	+209½	B.G.	+ 47½	G.B.	= 98	White	+262	Black
99	O.	+176	B.G.	+ 85	G.B.	=102	White	+258	Black
127	Y.O.	+100	B.G.	+133	G.B.	= 97	White	+263	Black
125	O.Y.	+ 20	B.G.	+215	G.B.	=122	White	+238	Black
148½	Y.	+100	G.B.	+111½	B.	=126	White	+234	Black
180	G.Y.	+ 90	V.	+ 90	B.V.	=138	White	+222	Black
138	Y.G.	+174	R.V.	+ 48	V.R.	=121	White	+239	Black
149	G.	+ 30	R.V.	+181	V.R.	= 84	White	+276	Black
160½	B.G.	+ 22	V.R.	+177½	R.	= 72	White	+288	Black
233	G.B.	+123	O.Y.	+ 4	Y.	=155	White	+205	Black
176	B.	+ 77½	Y.	+106½	G.Y.	=132	White	+228	Black
181½	V.B.	+ 59	Y.	+119½	G.Y.	=120	White	+240	Black
191	B.V.	+ 19	Y.	+150	G.Y.	=146	White	+214	Black
228½	V.	+ 85	G.Y.	+ 46½	Y.G.	=109	White	+251	Black
224½	R.V.	+ 28	G.Y.	+107½	Y.G.	=132	White	+228	Black
214½	V.R.	+ 40	B.G.	+105½	G.	= 65	White	+295	Black

TABLE XXIV.

Blue Background with Coloured Discs.

204½	R	+134	B.G.	+ 21½	G.B.	= 75	White+285	Black
133	O.R.	+193½	B.G.	+ 33½	G.B.	= 92	White+268	Black
108	R.O.	+204½	B.G.	+ 47½	G.B.	=103	White+257	Black
98	O.	+177	B.G.	+ 85	G.B.	=108	White+252	Black
116	Y.O.	+111	B.G.	+133	G.B.	= 90	White+270	Black
124	O.Y.	+ 21	B.G.	+215	G.B.	=115	White+245	Black
135	Y.	+113½	G.B.	+111½	B.	=149	White+211	Black
161	G.Y.	+109	V.	+ 90	B.V.	=145	White+215	Black
125	Y.G.	+187	R.V.	+ 48	V.R.	=121	White+239	Black
142	G.	+ 37	R.V.	+181	V.R.	= 94	White+266	Black
160½	B.G.	+ 22	V.R.	+177½	R.	= 88	White+272	Black
237	G.B.	+119	O.Y.	+ 4	Y.	=151	White+209	Black
184½	B.	+ 69	Y.	+106½	G.Y.	=126	White+234	Black
189½	V.B.	+ 51	Y.	+119½	G.Y.	=127	White+233	Black
195	B.V.	+ 15	Y.	+150	G.Y.	=145	White+215	Black
237½	V.	+ 76	G.Y.	+ 46½	Y.G.	=115	White+245	Black
224½	R.V.	+ 28	G.Y.	+107½	Y.G.	=121	White+239	Black
222½	V.R.	+ 32	B.G.	+105½	G.	= 71	White+289	Black

TABLE XXV.

Violet Background with Coloured Discs.

220½	R.	+118	B.G.	+ 21½	G.B.	= 70	White+290	Black
135	O.R.	+191½	B.G.	+ 33½	G.B.	=104	White+256	Black
114	R.O.	+198½	B.G.	+ 47½	G.B.	=124	White+236	Black
101	O.	+174	B.G.	+ 85	G.B.	= 98	White+262	Black
123	Y.O.	+104	B.G.	+133	G.B.	= 91	White+269	Black
125	O.Y.	+ 20	B.G.	+215	G.B.	=108	White+252	Black
144½	Y.	+104	G.B.	+111½	B.	=132	White+228	Black
130	G.Y.	+140	V.	+ 90	B.V.	=115	White+245	Black
135	Y.G.	+177	R.V.	+ 48	V.R.	=115	White+245	Black
133	G.	+ 46	R.V.	+181	V.R.	= 90	White+270	Black
155½	B.G.	+ 27	V.R.	+177½	R.	= 70	White+290	Black
231	G.B.	+125	O.Y.	+ 4	Y.	=150	White+210	Black
182½	B.	+ 71	Y.	+106½	G.Y.	=116	White+244	Black
190½	V.B.	+ 50	Y.	+119½	G.Y.	=118	White+242	Black
194	B.V.	+ 16	Y.	+150	G.Y.	=152	White+208	Black
235½	V	+ 78	G.Y.	+ 46½	Y.G.	=105	White+255	Black
229½	R.V.	+ 23	G.Y.	+107½	Y.G.	=107	White+253	Black
233½	V.R.	+ 21	B.G.	+105½	G.	= 66	White+294	Black

TABLE XXVI.

Red Background with Uncoloured Discs.

225½	R.	+ 113	B.G.	+ 21½	G.B.	= 76½	White + 283½	Black
135	O.R.	+ 190½	B.G.	+ 33½	G.B.	= 106	White + 254	Black
106	R.O.	+ 206½	B.G.	+ 47½	G.B.	= 117	White + 243	Black
103	O.	+ 172	B.G.	+ 85	G.B.	= 101	White + 259	Black
120	Y.O.	+ 107	B.G.	+ 133	G.B.	= 104	White + 256	Black
130	O.Y.	+ 15	B.G.	+ 215	G.B.	= 153	White + 207	Black
146½	Y.	+ 102	G.B.	+ 111½	B.	= 173	White + 187	Black
158	G.Y.	+ 112	V.	+ 90	B.V.	= 158	White + 202	Black
140	Y.G.	+ 172	R.V.	+ 48	V.R.	= 148	White + 212	Black
140	G.	+ 39	R.V.	+ 181	V.R.	= 109	White + 251	Black
160½	B.G.	+ 22	V.R.	+ 177½	R.	= 76	White + 284	Black
229	G.B.	+ 127	O.Y.	+ 4	Y.	= 163	White + 197	Black
176½	B.	+ 77	Y.	+ 106½	G.Y.	= 150	White + 210	Black
182½	V.B.	+ 58	Y.	+ 119½	G.Y.	= 135	White + 225	Black
182	B.V.	+ 28	Y.	+ 150	G.Y.	= 156	White + 204	Black
237½	V.	+ 76	G.Y.	+ 46½	Y.G.	= 129	White + 231	Black
225½	R.V.	+ 27	G.Y.	+ 107½	Y.G.	= 139	White + 221	Black
229½	V.R.	+ 25	B.G.	+ 105½	G.	= 96½	White + 263½	Black

TABLE XXVII.

Orange Background with Uncoloured Discs.

210½	R.	+ 128	B.G.	+ 21½	G.B.	= 95	White + 265	Black
133	O.R.	+ 193½	B.G.	+ 33½	G.B.	= 133	White + 227	Black
112	R.O.	+ 200½	B.G.	+ 47½	G.B.	= 145	White + 215	Black
115	O.	+ 160	B.G.	+ 85	G.B.	= 119	White + 241	Black
127	Y.O.	+ 100	B.G.	+ 133	G.B.	= 119	White + 241	Black
115	O.Y.	+ 30	B.G.	+ 215	G.B.	= 123	White + 237	Black
151½	Y.	+ 97	G.B.	+ 111½	B.	= 185	White + 175	Black
167	G.Y.	+ 103	V.	+ 90	B.V.	= 170	White + 190	Black
142	Y.G.	+ 170	R.V.	+ 48	V.R.	= 142	White + 218	Black
[illegible] 1	G.	+ 138	R.V.	+ 181	V.R.	= 124	White + 236	Black
[illegible]½	B.G.	+ 24	V.R.	+ 177½	R.	= 101	White + 259	Black
[illegible]	G.B.	+ 120	O.Y.	+ 4	Y.	= 188	White + 172	Black
[illegible]½	B.	+ 83	Y.	+ 106½	G.Y.	= 173	White + 187	Black
[illegible]0½	V.B.	+ 60	Y.	+ 119½	G.Y.	= 169	White + 191	Black
182	B.V.	+ 28	Y.	+ 150	G.Y.	= 176	White + 184	Black
138½	V.	+ 75	G.Y.	+ 46½	Y.G.	= 132	White + 228	Black
214½	R.V.	+ 39	G.Y.	+ 106½	Y.G.	= 164	White + 196	Black
210½	V.R.	+ 44	B.G.	+ 105½	G.	= 96	White + 264	Black

TABLE XXVIII.

Yellow Background with Uncoloured Discs.

220½	R.	+118	B.G.	+ 21½	G.B.	= 91	White+269	Black
132	O.R.	+194½	B.G.	+ 33½	G.B.	=132	White+228	Black
111	R.O.	+201½	B.G.	+ 47½	G.B.	=150	White+210	Black
121	O.	+154	B.G.	+ 85	G.B.	=136	White+224	Black
122	Y.O.	+105	B.G.	+133	G.B.	=133	White+227	Black
132	O.Y.	+ 13	B.G.	+215	G.B.	=162	White+198	Black
161½	Y	+ 87	G.B.	+111½	B.	=175	White+185	Black
158	G.Y.	+112	V.	+ 90	B.V.	=170	White+190	Black
141	Y.G.	+171	R.V.	+ 48	V.R.	=145	White+215	Black
143	G.	+ 36	R.V.	+181	V.R.	=130	White+230	Black
160½	B.G.	+ 22	V.R.	+177½	R.	= 95	White+265	Black
234	G.B.	+122	O.Y.	+ 4	Y.	=175	White+185	Black
161½	B.	+ 92	Y.	+106½	G.Y.	=181	White+179	Black
181½	V.B.	+ 59	Y.	+119½	G.Y.	=155	White+205	Black
168	B.V.	+ 42	Y.	+150	G.Y.	=175	White+185	Black
228½	V.	+ 85	G.Y.	+ 46½	Y.G.	=140	White+220	Black
227½	R.V.	+ 25	G.Y.	+107½	Y.G.	=139	White+221	Black
233	V.R.	+ 21½	B.G.	+105½	G.	= 95	White+265	Black

TABLE XXIX.

Green Background with Uncoloured Discs.

225½	R.	+113	B.G.	+ 21½	G.B.	= 95	White+265	Black
133	O.R.	+193½	B.G.	+ 33½	G.B.	=107	White+253	Black
105	R.O.	+207½	B.G.	+ 47½	G.B.	=145	White+215	Black
113	O.	+162	B.G.	+ 85	G.B.	=119	White+241	Black
126	Y.O.	+101	B.G.	+133	G.B.	=125	White+235	Black
128	O.Y.	+ 17	B.G.	+215	G.B.	=155	White+205	Black
162½	Y.	+ 86	G.B.	+111½	B.	=166	White+194	Black
168	G.Y.	+102	V.	+ 90	B.V.	=169	White+191	Black
125	Y.G.	+187	R.V.	+ 48	V.R.	=137	White+223	Black
138	G.	+ 41	R.V.	+181	V.R.	=116	White+244	Black
152½	B.G.	+ 30	V.R.	+177½	R.	= 89	White+271	Black
226	G.B.	+130	O.Y.	+ 4	Y.	=173	White+187	Black
166½	B.	+ 87	Y.	+106½	G.Y.	=165	White+195	Black
188½	V.B.	+ 52	Y.	+119½	G.Y.	=145	White+215	Black
172	B.V.	+ 38	Y.	+150	G.Y.	=162	White+198	Black
227½	V.	+ 86	G.Y.	+ 46½	Y.G.	=127	White+233	Black
224	R.V.	+ 28	G.Y.	+107½	Y.G.	=133	White+227	Black
227	V.R.	+ 27½	B.G.	+105½	G.	= 97½	White+262½	Black

TABLE XXX.

Blue Background with Uncoloured Discs.

216½ R.	+122 B.G.	+ 21½ G.B.	= 97½ White	+262½ Black
133 O.R.	+193½ B.G.	+ 33½ G.B.	=114 White	+246 Black
111 R.O.	+201½ B.G.	+ 47½ G.B.	=107 White	+253 Black
107 O.	+168 B.G.	+ 85 G.B.	= 98 White	+262 Black
133 Y.O.	+ 94 B.G.	+133 G.B.	=112 White	+248 Black
140 O.Y.	+ 5 B.G.	+215 G.B.	=126 White	+234 Black
161½ Y.	+ 87 G.B.	+111½ B.	=155 White	+205 Black
147 G.Y.	+123 V.	+ 90 B.V.	=138½ White	+221½ Black
132 Y.G.	+180 R.V.	+ 48 V.R.	=133 White	+227 Black
148 G.	+ 31 R.V.	+181 V.R.	=103 White	+257 Black
150½ B.G.	+ 32 V.R.	+177½ R.	= 82 White	+278 Black
231 G.B.	+125 O.Y.	+ 4 Y.	=168 White	+192 Black
173½ B.	+ 80 Y.	+106½ G.Y.	=140 White	+220 Black
185½ V.B.	+ 55 Y.	+119½ G.Y.	=136 White	+224 Black
181 B.V.	+ 29 Y.	+150 G.Y.	=160 White	+200 Black
233½ V.	+ 80 G.Y.	+ 46½ Y.G.	=115 White	+245 Black
225½ R.V.	+ 27 G.Y.	+107½ Y.G.	=138 White	+222 Black
224 V.R.	+ 30½ B.G.	+105½ G.	= 92 White	+268 Black

TABLE XXXI.

Violet Background with Uncoloured Discs.

208½ R.	+130 B.G.	+ 21½ G.B.	= 85 White	+275 Black
141 O.R.	+185½ B.G.	+ 33½ G.B.	=105 White	+255 Black
118 R.O.	+194½ B.G.	+ 47½ G.B.	=136 White	+224 Black
110 O.	+165 B.G.	+ 85 G.B.	=120 White	+240 Black
127 Y.O.	+100 B.G.	+133 G.B.	=115 White	+245 Black
134 O.Y.	+ 11 B.G.	+215 G.B.	=155 White	+205 Black
186½ Y.	+ 62 G.B.	+111½ B.	=147 White	+213 Black
160 G.Y.	+110 V.	+ 90 B.V.	=125 White	+235 Black
135 Y.G.	+177 R.V.	+ 48 V.R.	=143 White	+217 Black
139 G.	+ 40 R.V.	+181 V.R.	=111 White	+249 Black
153½ B.G.	+ 29 V.R.	+177½ R.	= 97 White	+263 Black
230 G.B.	+126 O.Y.	+ 4 Y.	=180 White	+180 Black
171½ B.	+ 82 Y.	+106½ G.Y.	=145 White	+215 Black
184½ V.B.	+ 56 Y.	+119½ G.Y.	=151 White	+209 Black
182 B.V.	+ 28 Y.	+150 G.Y.	=169 White	+191 Black
230 V.	+ 83½ G.Y.	+ 46½ Y.G.	=126 White	+234 Black
222½ R.V.	+ 30 G.Y.	+107½ Y.G.	=145 White	+215 Black
233½ V.R.	+ 21 B.G.	+105½ G.	= 83 White	+277 Black

TABLE XXXII.

Red Background for Coloured and Uncoloured Discs.

229½	R.	+109	B.G.	+ 21½	G.B.	= 70	White+290	Black
136	O.R.	+190½	B.G.	+ 33½	G.B.	=120	White+240	Black
114	R.O.	+198½	B.G.	+ 47½	G.B.	=115	White+245	Black
110	O.	+165	B.G.	+ 85	G.B.	=107	White+253	Black
122	Y.O.	+105	B.G.	+133	G.B.	= 95	White+265	Black
131	O.Y.	+ 14	B.G.	+215	G.B.	=134	White+226	Black
155½	Y.	+ 93	G.B.	+111½	B.	=138	White+222	Black
161	G.Y.	+109	V.	+ 90	B.V.	=138	White+222	Black
130	Y.G.	+182	R.V.	+ 48	V.R.	=128	White+232	Black
120	G.	+ 59	R.V.	+181	V.R.	=100	White+260	Black
150½	B.G.	+ 32	V.R.	+177½	R.	= 76	White+284	Black
223	G.B.	+133	O.Y.	+ 4	Y.	=163	White+197	Black
174½	B.	+ 79	Y.	+106½	G.Y.	=138	White+222	Black
182½	V.B.	+ 58	Y.	+119½	G.Y.	=142	White+218	Black
182	B.V.	+ 28	Y.	+150	G.Y.	=150	White+210	Black
227½	V.	+ 86	G.Y.	+ 46½	Y.G.	=115	White+245	Black
229½	R.V.	+ 23	G.Y.	+107½	Y.G.	=136	White+224	Black
236½	V.R.	+ 18	B.G.	+105½	G.	= 78	White+282	Black

TABLE XXXIII.

Orange Background for Coloured and Uncoloured Discs.

227½	R.	+111	B.G.	+ 21½	G.B.	= 77	White+283	Black
135	O.R.	+191½	B.G.	+ 33½	G.B.	= 97	White+263	Black
116	R.O.	+196½	B.G.	+ 47½	G.B.	=100	White+260	Black
115	O.	+160	B.G.	+ 85	G.B.	=113	White+247	Black
127	Y.O.	+100	B.G.	+133	G.B.	=120	White+240	Black
133	O.Y.	+ 12	B.G.	+215	G.B.	=113	White+247	Black
144½	Y.	+104	G.B.	+111½	B.	=128	White+232	Black
177	G.Y.	+ 93	V.	+ 90	B.V.	=165	White+195	Black
135	Y.G.	+177	R.V.	+ 48	V.R.	=131	White+229	Black
140	G.	+139	R.V.	+181	V.R.	=107	White+253	Black
152½	B.G.	+ 30	V.R.	+177½	R.	= 80	White+280	Black
225	G.B.	+131	O.Y.	+ 4	Y.	=152	White+208	Black
170½	B.	+ 83	Y.	+106½	G.Y.	=135	White+225	Black
185½	V.B.	+ 55	Y.	+119½	G.Y.	=139	White+221	Black
180	B.V.	+ 30	Y.	+150	G.Y.	=141	White+219	Black
225½	V.	+ 88	G.Y.	+ 46½	Y.G.	=119	White+241	Black
227½	R.V.	+ 25	G.Y.	+107½	Y.G.	=127	White+233	Black
231	V.R.	+105½	G.	+ 23½	B.G.	= 88	White+272	Black

TABLE XXXIV.

Yellow Background for Coloured and Uncoloured Discs.

221½	R.	+117	B.G.	+ 21½	G.B.	= 70	White+290	Black
136	O.R.	+190½	B.G.	+ 33½	G.B.	= 97	White+263	Black
113	R.O.	+199½	B.G.	+ 47½	G.B.	=105	White+255	Black
110	O.	+165	B.G.	+ 85	G.B.	=106	White+254	Black
130	Y.O.	+ 97	B.G.	+133	G.B.	=117	White+243	Black
129	O.Y.	+ 16	B.G.	+215	G.B.	=162	White+198	Black
141½	Y.	+107	G.B.	+111½	B.	=145	White+215	Black
177½	G.Y.	+ 92½	V.	+ 90	B.V.	=146	White+214	Black
134	Y.G.	+178	R.V.	+ 48	V.R.	=137	White+223	Black
139	G.	+ 40	R.V.	+181	V.R.	=105	White+255	Black
157½	B.G.	+ 25	V.R.	+177½	R.	= 85	White+275	Black
223	G.B.	+133	O.Y.	+ 4	Y.	=175	White+185	Black
165½	B.	+ 88	Y.	+106½	G.Y.	=160	White+200	Black
182½	V.B.	+ 58	Y.	+119½	G.Y.	=139	White+221	Black
180	B.V.	+ 30	Y.	+150	G.Y.	=165	White+195	Black
230	V.	+ 83½	G.Y.	+ 46½	Y.G.	=115	White+245	Black
228½	R.V.	+ 24	G.Y.	+107½	Y.G.	=114	White+246	Black
227	V.R.	+ 27½	B.G.	+105½	G.	= 86	White+274	Black

TABLE XXXV.

Green Background for Coloured and Uncoloured Discs.

225	R.	+113½	B.G.	+ 21½	G.B.	= 77½	White+282½	Black
122	O.R.	+204½	B.G.	+ 33½	G.B.	= 90	White+270	Black
105	R.O.	+207½	B.G.	+ 47½	G.B.	=120	White+240	Black
106	O.	+169	B.G.	+ 85	G.B.	=102	White+258	Black
108	Y.O.	+119	B.G.	+133	G.B.	=109	White+251	Black
128	O.Y.	+ 17	B.G.	+215	G.B.	=145	White+215	Black
139	Y.	+109½	G.B.	+111½	B.	=138	White+222	Black
164	G.Y.	+106	V.	+ 90	B.V.	=142	White+218	Black
139	Y.G.	+173	R.V.	+ 48	V.R.	=126	White+234	Black
146	G.	+ 33	R.V.	+181	V.R.	= 95	White+265	Black
160½	B.G.	+ 22	V.R.	+177½	R.	= 75	White+285	Black
231	G.B.	+125	O.Y.	+ 4	Y.	=147	White+213	Black
173½	B.	+ 80	Y.	+106½	G.Y.	=147	White+213	Black
188½	V.B.	+ 52	Y.	+119½	G.Y.	=127	White+233	Black
190	B.V.	+ 20	Y.	+150	G.Y.	=148	White+212	Black
225½	V.	+ 88	G.Y.	+ 46½	Y.G.	=129	White+231	Black
224½	R.V.	+ 28	G.Y.	+107½	Y.G.	=125	White+235	Black
218½	V.R.	+ 36	B.G.	+105½	G.	= 78	White+282	Black

TABLE XXXVI.

Blue Background for Coloured and Uncoloured Discs.

220½	R.	+118	B.G.	+ 21½	G.B.	= 79	White+281	Black
122	O.R.	+204½	B.G.	+ 33½	G.B.	=125	White+235	Black
106	R.O.	+206½	B.G.	+ 47½	G.B.	=107	White+253	Black
99	O.	+176	B.G.	+ 85	G.B.	= 96	White+264	Black
109	Y.O.	+118	B.G.	+133	G.B.	= 97	White+263	Black
132	O.Y.	+ 13	B.G.	+215	G.B.	=112	White+248	Black
148½	Y.	+100	G.B.	+111½	B.	=134	White+226	Black
170	G.Y.	+100	V.	+ 90	B.V.	=134½	White+225½	Black
135	Y.G.	+177	R.V.	+ 48	V.R.	=126	White+234	Black
148	G.	+ 31	R.V.	+181	V.R.	=105	White+255	Black
157½	B.G.	+ 25	V.R.	+177½	R.	= 75	White+285	Black
231	G.B.	+125	O.Y.	+ 4	Y.	=150	White+210	Black
183½	B.	+ 70	Y.	+106½	G.Y.	=138	White+222	Black
190½	V.B.	+ 50	Y.	+119½	G.Y.	=137	White+223	Black
191	B.V.	+ 19	Y.	+150	G.Y.	=138	White+222	Black
224½	V.	+ 89	G.Y.	+ 46½	Y.G.	=115	White+245	Black
222½	R.V.	+ 30	G.Y.	+107½	Y.G.	=131	White+229	Black
227½	V.R.	+ 27	B.G.	+105½	G.	= 75	White+285	Black

TABLE XXXVII.

Violet Background for Coloured and Uncoloured Discs.

209½	R.	+129	B.G.	+ 21½	G.B.	= 74	White+286	Black
133	O.R.	+193½	B.G.	+ 33½	G.B.	=110	White+250	Black
116	R.O.	+196½	B.G.	+ 47½	G.B.	=111	White+249	Black
102	O.	+173	B.G.	+ 85	G.B.	= 94	White+266	Black
125	Y.O.	+102	B.G.	+133	G.B.	=103	White+257	Black
137	O.Y.	+ 8	B.G.	+215	G.B.	=137	White+223	Black
178½	Y.	+ 70	G.B.	+111½	B.	=152	White+208	Black
116	G.Y.	+154	V.	+ 90	B.V.	=112	White+248	Black
133	Y.G.	+179	R.V	+ 48	V.R.	=131	White+229	Black
140	G	+ 39	R.V.	+181	V.R.	= 85	White+275	Black
153½	B.G.	+ 29	V.R.	+177½	R.	= 75	White+285	Black
233	G.B.	+123	O.Y.	+ 4	Y.	=156	White+204	Black
175½	B.	+ 78	Y.	+106½	G.Y.	=132	White+228	Black
184½	V.B.	+ 56	Y.	+119½	G.Y.	=131	White+229	Black
181	B.V.	+ 29	Y.	+150	G.Y.	=140	White+220	Black
233½	V.	+ 80	G.Y.	+ 46½	Y.G.	=115	White+245	Black
222½	R.V.	+ 30	G.Y.	+107½	Y.G.	=111	White+249	Black
227½	V.R.	+ 27	B.G.	+105½	G.	= 71	White+289	Black

A careful consideration of these results reveals some interesting facts about complementarism as it is influenced by colour contrast. Thus in the first set of experiments (coloured backgrounds with coloured discs), the following features were very noticeable: When the background was of the same quality as that of the colour of which the complementary was sought, the equation showed a marked increase in the degrees of that quality and a corresponding decrease in the degrees of the complementary. For example, under former conditions, 100° of orange were required with the complementary to produce the grey. With the orange background 131° are necessary, while with blue background only 98°. If the background be a quality different from either the colour or its complementary, then whether there will be an increase or decrease in the number of degrees of either will depend upon which of the two qualities the background is nearer to in the colour circle. The increase or decrease will be somewhat proportional to that distance. If the background be about equidistant from each, the results show an indifference. The following Table (XXXVIII) will exhibit this variation concisely.

TABLE XXXVIII.

Colour	Backgrounds											
	Red		Orange		Yellow		Green		Blue		Violet	
	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease
R	11	..	2	..	1	..		2	..	14	2	..
O.R	10	..	8	..	1	..		12	..	1	1	..
R.O	1	..	1	..	..	4		11	..	6		..
O	5	..	31	..	19	..		1	..	2	1	..
Y.O	11	..	12	..	3	..	6	..	..	5	2	..
O.Y	6	..	4	..	1	..	..	3	..	4	..	3
Y	2	..	..	½	18	..	8	..	..	5½	4	..
G.Y	..	..	10	..	18	..	20	..	1	..	..	30
Y.G	..	5	3	..	5	..	1	..	..	12	..	2
G	..	4	..	..	..	13	7	..	..	..	..	9
B.G	..	1½	..	1	..	5½	5	..	5	..	..	..
G.B	..	8	..	5	..	7	3	..	7	..	1	..
B	3½	..	..	11	..	7	1½	..	9	..	7	..
V.B	..	6	..	4	..	3	..	7	1	..	2	..
B.V	..	19	..	12	..	30	..	3	1	..	..	4
V	..	2	4	..	..	3	..	2	7	..	5	..
R.V	..	..	..	2	..	10	..	3	..	3	2	..
V.R	3	..	½	..	..	½	..	16	..	8	3	..

It will be seen that the greatest changes occur in the equations for orange, yellow, green-yellow, and blue-violet with the brighter backgrounds. With the darker backgrounds, blue and violet, the differences are less, although sufficiently marked to show the orderliness of contrast effects. In case the background is distinctly different in quality from either the colour or its complementary, the variations are small and may show either an increase or a decrease. This is seen in equations 1, 2, and 3 with yellow background, or in 4, 5, and 6 with green background.

Table XXXIX indicates the variations for the white disc when the coloured backgrounds are used with the coloured discs only. Whenever the brighter colour-qualities are used as backgrounds there is a decided decrease in the number of degrees of the white, (e.g., in the case of yellow, orange, and green backgrounds). This is to be expected when the darker quality is induced upon the coloured discs. Yet the opposite of this is only partially the case. If we take the instance of the violet background, inducing as it does a greenish yellow, and thus requiring more of violet or of the neighbouring quality in the equation, there is a consequent lessening of the light intensity with the increase of the darker quality. In the other instances the indifference is indicated by the slight irregularities in increase or decrease.

TABLE XXXIX.

Influence of the Coloured Background behind the Coloured Discs on the Intensity.

Equation for	Increase or Decrease of White with each Background.											
	Red		Orange		Yellow		Green		Blue		Violet	
	Incr.	Decr.	Incr.	Decr.	Incr.	Decr.	Incr.	Decr.	Incr.	Decr.	Incr.	Decr.
R.	..	25	..	..	..	5	6½	..	5	..	..	..
O. R.	12	..	..	13	..	18	1	..	5	..	17	..
R. O.	10	..	6	..	..	25	..	9	..	4	17	..
O.	..	27	..	5	..	12	..	1	5	..	..	5
Y. O.	..	..	65	..	..	35	..	18	..	25	..	24
O. Y.	..	5	..	12	..	3	..	18	..	25	..	32
Y.	..	15	..	3	..	14	..	28	..	5	..	22
G. Y.	..	..	..	..	..	12	1	..	8	..	..	22
Y. G.	..	13	..	10	..	21	..	18	..	18	..	24
G.	..	13	..	14	..	31	..	19	..	9	..	13
B. G.	3	..	..	20	..	20	..	6	10	..	..	8
G. B.	1	..	..	8	..	28	..	5	..	9	..	10
B.	..	40	..	14	..	35	..	13	..	19	..	29
V. B.	10	..	..	1	..	24	..	5	2	..	..	7
B. V.	..	..	..	31	..	11	..	6	..	7	..	..
V.	..	14	..	10	..	1	..	10	..	4	..	14
R. V.	35	..	21	..	..	0	17	..	6	..	..	8
V. R.	..	..	10	..	..	25	..	15	..	9	..	14

A marked feature of the second set of contrast experiments (in which the coloured backgrounds were used only with the uncoloured discs) consisted in the fact that the background induced the colour of its complementary upon the uncoloured discs. Thus a blue background gave a yellowish tinge to the grey. This had a noticeable effect on the other side of the equation, as it called for a corresponding increase in the colour quality which had been induced upon the grey. But if this induced colour did not approximate to either colour quality in the equation, much difficulty was experienced in obtaining an equation, and the results show many irregularities. A variation in the intensity was also noticeable. With the dull black background fewer degrees of white were almost invariably required. With the brighter colour-qualities (e.g., yellow) as backgrounds there was necessary a decided increase in the degrees of the white sector. This may be seen in Table XL.

TABLE XL

Equation for	Backgrounds						
	Dull Black	Red	Orange	Yellow	Green	Blue	Violet
	Degrees of White	Degrees of White	Degrees of White	Degrees of White	Degrees of White	Degrees of White	Degrees of White
R.	70	76½	95	91	95	97½	85
O.R.	87	106	133	132	107	114	105
R.O.	107	117	145	150	145	107	136
O.	103	101	119	136	119	98	120
Y.O.	115	104	119	133	125	112	115
O.Y.	140	153	123	162	155	126	155
Y.	154	173	185	175	166	155	147
G.Y.	137	158	170	170	169	138½	125
Y.G.	139	148	142	145	137	133	143
G.	103	109	124	130	116	103	111
B.G.	78	76	101	95	89	82	97
G.B.	160	163	188	175	173	168	180
B.	145	150	173	181	165	140	145
V.B.	125	135	169	155	145	136	151
B.V.	152	156	176	175	162	160	169
V.	119	129	132	140	127	115	126
R.V.	115	139	164	139	133	138	145
V.R.	80	96½	96	95	97½	92	83

When the large coloured backgrounds were used for both sets of discs, the variations in the coloured sectors corresponded very nearly to those observed when the smaller coloured backgrounds were used with these alone. This may be seen by a glance at Table XLI. A comparison of this with Table XXXVIII will reveal very similar results; but, while the variations in the former (XLI) are usually greater, the size of the backgrounds was not increased sufficiently to make this a striking feature in the results.

The variations in intensities are indicated in Table XLII, which states the increase or decrease in the degrees of the white sector. Here the irregularities are somewhat more numerous, as might be expected, since it was much more difficult to judge an equality of intensity under these conditions of both light and colour contrast. With a bright background (e.g., yellow) there was usually a considerable increase in the degrees of the white sector, whereas with the blue and the violet (being qualities of lower intensity) a decrease was generally required. Red, orange, and green backgrounds are accompanied by considerable irregularity of variation, but this is due partly to the fact that the light contrast was less strong, and partly to the fact that the colour induced upon the uncoloured ... accurate observation more difficult.

TABLE XLI.

Colour	Red Increase.	Red Decrease.	Orange Increase.	Orange Decrease.	Yellow Increase.	Yellow Decrease.	Green Increase.	Green Decrease.	Blue Increase.	Blue Decrease.	Violet Increase.	Violet Decrease.	Complementary between
R......	11	..	[illegible]	..	[illegible]		6½	..	2	..	..	9	B.G. and G.B.
O.R...	2	..	1				..	12	..	12	..	1	B.G. " G.B.
R.O..	..	..	2	.			.	9	..	8	2	..	B.G. " G.B.
O......	10	..	15	.	10	..	6	..	1	..	2	..	B.G. " G.B.
Y.O....	1	..	6	.	[illegible]	..	..	13	..	12	4	..	B.G. " G.B.
O.Y...	3	..	5	.		..	..	..	4	..	9	..	B.G. " G.B.
Y......	15		4			..	..	1½	..	8	38½	..	G.B. " B.
G.Y	1	.	17	..	17½	..	4	..	10	..	..	44	B.V. " V.
Y.G	.	7		2	.	3	2	..	..	2	..	4	R.V. " V.R.
[illegible]	..	22	..	2	.	3	4	..	6	..	..	2	R.V. " V.R.
[illegible]		5	.	3	2	..	5	..	2	..	..	2	V.R. " R.
[illegible]		7	.	5	..	7	1	..	1	..	3	..	O.Y. " Y.
[illegible]		1	..	5	..	10	..	2	8	..		..	Y. " G.Y.
[illegible]	..	[illegible]	..	3	..	6	..	..	2	..	..	4	Y. " G.Y.
B.V	.	12	..	4	..	14	..	4	..	3	..	13	Y. " G.Y.
V	.	3	.	5	.	½	5	..	..	6	3	..	G.Y. " Y.G.
R.V	2	.	..			..	..	3	..	5	5	..	G.Y. " Y.G.
V.R	6	..	½		..	3½	..	12	..	3	..	3	G. " B.G.

TABLE XLII.

Equation for	Increase or Decrease of White with the following Backgrounds: Red. Increase.	Red. Decrease.	Orange. Increase.	Orange. Decrease.	Yellow. Increase.	Yellow. Decrease.	Green. Increase.	Green. Decrease.	Blue. Increase.	Blue. Decrease.	Violet. Increase.	Violet. Decrease.	Complementary between
R....	7	..	7	..	..	..	7½	..	9	..	4	..	B.G. and G.B.
Q.R....	..	23	10	..	10	..	3	..	38	..	23	..	B.G. " G.B.
R.O....	..	15	..	7	..	2	13	..	..	..	4	..	B.G. " G.B.
O.	6	..	10	..	3	..	..	1	..	7	..	9	B.G. " G.B.
Y.O. ...	25	..	5	..	2	..	..	6	..	8	..	12	B.G. " G.B.
O.Y. ...	..	21	..	27	22	..	5	..	..	28	..	3	B.G. " G.B.
Y.	..	10	..	26	..	9	..	16	..	20	..	2	G.B. " B.
G.Y. ...	27	..	28	..	9	..	5	..	..	2½	..	25	B.V. " V.
Y.G. ...	3	..	..	8	..	2	..	13	..	13	..	8	R.V. " V.R.
G.	7	..	4	..	2	..	..	8	2	..	..	18	R.V. " V.R.
B.G. ...	4	..	2	..	7	..	..	3	..	3	..	3	V.R. " R.
G.B. ...	..	11	..	8	15	..	..	13	..	10	..	4	O.Y. " Y.
B.	..	3	..	10	15	..	2	..	..	7	..	13	Y. " G.Y.
V.B. ...	..	3	14	..	14	..	2	..	12	..	6	..	Y. " G.Y.
B.V. ...	..	9	..	11	13	..	..	4	..	14	..	12	Y. " G.Y.
V.	4	..	..	..	..	4	10	..	..	4	..	4	G.Y. " Y.G.
R.V. ...	..	9	12	..	..	1	10	.	16	..	..	4	G.Y. " Y.G.
V.R. ...	10	..	8	..	..	6	..	2	..	5	..	9	G. " B.G.

IV.

COMPLEMENTARISM IN LOWER LIGHT INTENSITIES.

Thus far our attention has been directed to the complementary relations of colours as ascertained in ordinary daylight. When we seek to discern the effects of the different intensities of light upon complementarism, the problem is at once very much enlarged. Investigation has shown that the manifoldness of qualities decreases with the approach to the extremes of light intensities. "This change of colour, the saturation being constant, is only within certain limits independent of the intensity, and, in the most recent spacial representation of light and colour sensation, is provided for by giving the base of the colour-cone an inclination towards the axis, so that yellow occupies the highest, blue-violet the lowest, position."* As Kirschmann points out,† "The only pair of complementary colours which have their maximum saturation at equal intensities must therefore be at the ends of that diameter of the base which stands at right angles to the axis, and this condition will be satisfied somewhere near red and blue-green." A bright illumination causes all colours to tend somewhat toward yellow in quality. Helmholtz‡ has made similar observations on the pure colours of the prismatic spectrum, and has found that even they undergo analogous changes. The violet of the spectrum is affected by a very slight variation in the intensity of light. In feeble illumination it approaches purple in hue; as the illumination increases the colour changes to blue, and finally to a whitish-grey, with a faint tint of violet-blue. Green, as it is made brighter, passes into yellowish-green, and then into whitish yellow; for actual conversion into white, it is necessary that the illumination should be dazzling. Red seems to resist these changes more than the other colours; but if it be made quite bright, it passes into orange and then into bright yellow.

Changes of illumination in the other direction produce effects which are quite as remarkable. If we arrange by ordinary daylight sheets of red and blue paper which have the same degree of brightness and then carry them into a darkened room, we shall be surprised to find that the blue paper appears very much brighter than the red. Indeed, the room may be darkened so as to cause the red to appear black, while the blue still plainly retains its colour. By similar experiments, it can be shown that red, yellow, and orange-coloured surfaces are relatively brighter when exposed to a bright light than blue; but the latter, on the other hand, has the advantage when the illumination is feeble. It follows from this that photometric comparisons of the brightness of differently coloured surfaces, if made under bright day-

* Wilson, *On Colour Photometry, etc.* (University of Toronto Studies, Psychological Series, Vol. II, p. 47).

† *Colour Saturation* (American Journal of Psychology, Vol. VII, p. 394.)

‡ *Physiological Optics*, p. 297.

light, will no longer hold good in a dark day or in twilight, and that consequently we cannot, under a certain illumination, establish photometric relations that shall hold good under all other illuminations. This subject has been discussed at length by Kirschmann,* and later by Gruber.† In the psychological laboratory of the University of Toronto the intensity of coloured pigment papers under different illuminations has been experimentally investigated by Mr. R. J. Wilson.‡

Wilson found that uniformly there was no diminution of intensity with the blue in the case of decrease in the illumination; on the contrary, in most cases the number of the degrees of white was highest in lowest illumination. In the blue-green, the tendency was rather a decrease in the number of degrees from full intensity down to 20 tissues covering the aperture, and from that to the lowest intensity of light a steady increase in every case. At 30 tissues, the colour appeared far more blue than green. Violet showed a consistent downward tendency with the decrease of illumination. This was the case also with green till 30 papers controlled the illumination; but when colour was no longer present, the number of degrees rose, when 30, 40, and 50 papers respectively covered the aperture. The tendency downward in red was in every case observable. Red and orange-red became dark quickly, and lost their colour-quality when 20 tissues were used. Orange revealed the same tendency, but not to such a marked degree. Yellow was for all observers very difficult to judge, ranging from nearly cream colour in lowest intensity through a yellow with a tinge of orange in it up to a bright yellow.

Our efforts in this instance were to determine the effects of the lower light intensities upon the complementary relations of colours. The pigment papers used were those of the Milton-Bradley system (which papers had been used also by Wilson in his investigations of the phenomenon of Purkinje). The condi-

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* Kirschmann, *Ueber die quantitativen Verhältnisse des simultanen Contrastes.* (Philosophische Studien, Vol. VI, p. 10.)

† Gruber, *Untersuchungen über die Helligkeit der Farben.* (Philosophische Studien, Vol. IX, p. 429.)

‡ *On Colour Photometry and on some Quantitative Relations of the Phenomenon of Purkinje.* (University of Toronto Studies, Psych. Series, Vol. II., p. 47.)

tions under which the experiments were performed were similar to those already described. except for the differences in the amount of light admitted to the room. In this case the light entered through an opening 10 inches by 12 inches, parallel to the plane of the discs. The intensity of the light admitted was regulated by covering the aperture in successive experiments with sheets of tissue papers, arranged in frames, viz., 2, 10, 20, 30. 40, 50, 60, 70 tissues. In no instance could colour be discerned when more than 60 tissues were used. In most cases it was not observable beyond 40 tissues. The limit in each case is indicated by the horizontal line of division in each division of the Table. The following equations show the variations in the complementary relations under these conditions:

TABLE XLIII.

Equation I.

	Red	Blue-Green	Green-Blue	White	Black
Ordinary light..	211	+ 127	+ 22	= 67	+293
2 Tissues.....	211	+ 127	+ 22	= 87	+273
10 "	197	+ 141	+ 22	= 82	+278
20 "	197	+ 141	+ 22	= 88	+272
30 "	197	+ 141	+ 22	= 94	+266
40 "	225	+ 131	+ 22	= 83	+277
50 "	230	+ 108	+ 22	= 70	+290
60 "	230	+ 108	+ 22	= 62	+298
70 "	....	Invisible			

Equation II.

	Orange-Red	Green-Blue	Blue-Green	White	Black
Ordinary light..	143	+ 33	+ 184	= 84	+276
2 Tissues.....	145	+ 33	+ 182	= 98	+262
10 "	141	+ 33	+ 186	=108	+252
20 "	148	+ 33	+ 179	=119	+241
30 "	160	+ 33	+ 167	=101	+259
40 "	174	+ 33	+ 153	= 97	+263
50 "	185	+ 33	+ 142	= 86	+274
60 " ..	188	+ 33	+ 139	= 76	+284
70 " .	....	Invisible			

Equation III.

	Red-Orange	Blue-Green	Green-Blue	White	Black
Ordinary light	113	+ 199	+ 48	= 91	+ 269
2 Tissues	109	+ 203	+ 48	= 112	+ 248
10 "	103	+ 209	+ 48	= 123	+ 237
20 "	114	+ 198	+ 48	= 123	+ 237
30 "	161	+ 151	+ 48	= 109	+ 251
40 "	166	+ 146	+ 48	= 105	+ 255
50 "	166	+ 146	+ 48	= 100	+ 260
60 "	166	+ 146	+ 48	= 100	+ 260
70 "	....	Invisible			

Equation IV.

	Orange	Blue-Green	Green-Blue	White	Black
Ordinary light	99	176	+ 85	= 120	+ 240
2 Tissues	100	+ 176	+ 84	= 121	+ 239
10 "	101	+ 176	+ 83	= 115	+ 245
20 "	107	+ 176	+ 77	= 110	+ 250
30 "	114	+ 176	+ 70	= 108	+ 252
40 "	119	+ 176	+ 65	= 111	+ 249
50 "	119	+ 176	+ 65	= 100	+ 260
60 "	119	+ 176	+ 65	= 95	+ 265
70 "	....	Invisible			

Equation V.

	Yellow-Orange	Blue-Green	Green-Blue	White	Black
Ordinary light	103	+ 122	+ 135	= 104	+ 256
2 Tissues	113	+ 122	+ 125	= 121	+ 239
10 "	101	+ 122	+ 137	= 130	+ 230
20 "	107	+ 122	+ 131	= 136	+ 224
30 "	109	+ 122	+ 129	= 108	+ 252
40 "	114	+ 122	+ 124	= 92	+ 268
50 "	112	+ 122	+ 126	= 109	+ 251
60 "	112	+ 122	+ 126	= 109	+ 251
70 "	....	Invisible			

Equation VI.

	Orange-Yellow	Blue-Green	Green-Blue	White	Black
Ordinary light	124	+ 5	+ 231	=139	+221
2 Tissues	122	+ 5	+ 233	=148	+212
10 "	121	+ 5	+ 234	=142	+218
20 "	113	+ 5	+ 242	=142	+218
30 "	122	+ 5	+ 233	=154	+206
40 "	140	+ 5	+ 215	=150	+210
50 "	140	+ 5	+ 215	=143	+217
60 "	140	+ 5	+ 215	=136	+224
70 "	....	Invisible			

Equation VII.

	Yellow	Green-Blue	Blue	White	Black
Ordinary light..	155	+ 113	+ 92	=128	+232
2 Tissues.....	150	+ 113	+ 97	=145	+215
10 "	157	+ 113	+ 90	=158	+202
20 "	160	+ 113	+ 87	=158	+202
30 "	175	+ 113	+ 72	=133	+227
40 "	167	+ 113	+ 80	=132	+228
50 "	167	+ 113	+ 80	=125	+235
60 "	167	+ 113	+ 80	=125	+235
70 "	....	Invisible			

Equation VIII.

	Green-Yellow	Blue-Violet	Violet	White	Black
Ordinary light..	147	+ 90	+ 123	=136½	+223½
2 Tissues......	151	+ 86	+ 123	=123	+237
10 "	122	+ 115	+ 123	=124	+236
20 "	115	+ 122	+ 123	=119	+241
30 "	107	+ 130	+ 123	=114	+246
40 "	107	+ 130	+ 123	=115	+245
50 "	107	+ 130	+ 123	=101	+259
60 "	....	Invisible			

Equation IX.

	Yellow-Green	Red-Violet	Violet-Red	White	Black
Ordinary light..	122	+ 190	+ 48	= 137	+ 223
2 Tissues.....	124	+ 188	+ 48	= 133	+ 227
10 "	118	+ 194	+ 48	= 141	+ 219
20 "	115	+ 197	+ 48	= 133	+ 227
30 "	89	+ 223	+ 48	= 122	+ 238
40 "	65	+ 247	+ 48	= 109	+ 251
50 "	53	+ 259	+ 48	= 99	+ 261
60 "	53	+ 259	+ 48	= 95	+ 265
70 "	....	Invisible			

Equation X.

	Green	Red-Violet	Violet-Red	White	Black
Ordinary light..	131	+ 48	+ 181	= 92	+ 268
2 Tissues.....	131	+ 48	+ 181	= 92	+ 268
10 "	130	+ 49	+ 181	= 87	+ 273
20 "	124	+ 55	+ 181	= 88	+ 272
30 "	128	+ 51	+ 181	= 90	+ 270
40 "	141	+ 38	+ 181	= 90	+ 270
50 "	127	+ 5[illegible]	+ 181	= 91	+ 269
60 "	114	+ 65	+ 181	= 89	+ 271
70 "	....	Invisible			

Equation XI.

	Blue-Green	Violet-Red	Red	White	Black
Ordinary light.	144	+ 34	+ 182	= 82	+ 278
2 Tissues	147	+ 34	+ 179	= 93	+ 267
10 "	148	+ 34	+ 178	= 96	+ 264
20 "	146	+ 34	+ 180	= 98	+ 262
30 "	135	+ 34	+ 191	= 89	+ 271
40 "	128	+ 34	+ 198	= 88	+ 272
50 "	121	+ 34	+ 205	= 92	+ 268
60 "	121	+ 34	+ 205	= 87	+ 273
70 "	....	Invisible			

Equation XII.

	Green-Blue	Orange-Yellow	Yellow	White	Black
Ordinary light.	238	+ 118	+ 4	= 141	+ 219
2 Tissues	241	+ 115	+ 4	= 146	+ 214
10 "	244	+ 112	+ 4	= 142	+ 218
20 "	248	+ 108	+ 4	= 138	+ 222
30 "	254	+ 102	+ 4	= 138	+ 222
40 "	238	+ 118	+ 4	= 146	+ 214
50 "	223	+ 133	+ 4	= 151	+ 209
60 "	232	+ 124	+ 4	= 159	+ 201
70 "	....	Invisible			

Equation XIII.

	Blue	Yellow	Green-Yellow	White	Black
Ordinary light	184	+ 69	+ 107	= 147	+ 213
2 Tissues	188	+ 69	+ 103	= 129	+ 231
10 "	174	+ 69	+ 117	= 134	+ 226
20 "	199	+ 69	+ 92	= 134	+ 226
30 "	186	+ 69	+ 105	= 139	+ 221
40 "	203	+ 69	+ 88	= 137	+ 223
50 "	205	+ 69	+ 86	= 137	+ 223
60 "	205	+ 69	+ 86	= 137	+ 223
70 "	....	Invisible			

Equation XIV.

	Violet-Blue	Yellow	Green-Yellow	White	Black
Ordinary light	187	+ 43	+ 130	= 127	+ 233
2 Tissues	198	+ 43	+ 119	= 142	+ 218
10 "	212	+ 43	+ 105	= 122	+ 238
20 "	233	+ 43	+ 84	= 121	+ 239
30 "	227	+ 43	+ 90	= 113	+ 247
40 "	229	+ 43	+ 88	= 112	+ 248
50 "	206	+ 43	+ 111	= 121	+ 239
60 "	206	+ 43	+ 111	= 121	+ 239
70 "	....	Invisible			

Equation XV.

	Blue-Violet	Yellow	Green-Yellow	White	Black
Ordinary light..	189	+ 16	+ 155	=137	+223
2 Tissues.....	188	+ 16	+ 156	=169	+191
10 "	195	+ 16	+ 149	=147	+213
20 "	201	+ 16	+ 143	=150	+210
30 "	207	+ 16	+ 137	=138	+222
40 "	214	+ 16	+ 130	=138	+222
50 "	214	+ 16	+ 130	=128	+232
60 "	214	+ 16	+ 130	=119	+241
70 "	....	Invisible			

Equation XVI.

	Violet	Green-Yellow	Yellow-Green	White	Black
Ordinary light..	236	+ 78	+ 46	=112	+248
2 Tissues.....	227	+ 78	+ 55	=117	+243
10 "	244	+ 78	+ 38	=116	+244
20 "	250	+ 78	+ 32	=109	+251
30 "	263	+ 78	+ 19	=107	+253
40 "	271	+ 78	+ 11	= 97	+263
50 "	278	+ 78	+ 4	= 91	+269
60 "	282	+ 78		= 85	+275
70 "	284	+ 76		= 83	+277

Equation XVII.

	Red-Violet	Green-Yellow	Yellow-Green	White	Black
Ordinary light	222	+ 27	+ 111	=137	+223
2 Tissues	213	+ 27	+ 120	=142	+218
10 "	239	+ 27	+ 94	=132	+228
20 "	246	+ 27	+ 87	=121	+239
30 "	258	+ 27	+ 75	=112	+248
40 "	269	+ 27	+ 64	=102	+258
50 "	269	+ 27	+ 64	=107	+253
60 "	269	+ 27	+ 64	=117	+243
70 "	....	Invisible			

Equation XVIII.

	Violet-Red		Green		Blue-Green	White	Black
Ordinary light	231	+	103	+	26	= 76	+284
2 Tissues	225	+	109	+	26	= 86	+274
10 "	229	+	105	+	26	= 76	+284
20 "	237	+	97	+	26	= 74	+286
30 "	244	+	90	+	26	= 69	+291
40 "	256	+	78	+	26	= 63	+297
50 "	263	+	71	+	26	= 63	+297
60 "	263	+	71	+	26	= 57	+303
70 "	....		Invisible				

In the case of the equations for red, orange-red, red-orange, and orange, there was a decided increase in the number of degrees of these colours required as the illumination was made less intensive. This was obviously because the complementaries (between blue-green and green-blue) have a much higher intensity and saturation relatively under the weaker illumination. This increase, however, was not regular, except beyond 20 tissues. From ordinary daylight to the 20 tissues there was usually a somewhat regular decrease in the number of degrees of these qualities. This agrees very decidedly with the results of Wilson as to the effects of lower intensities of light on these colours. In Equations V, VI, and VII, the same variations were observable with yellow-orange, orange-yellow, and yellow, but the increases were not so large. In Equation VII it is seen that less blue is required, and the corresponding increase in the yellow is necessary.

In the case of the Equations for green-yellow, yellow-green, green, and blue-green, the decrease in number of degrees required under weak illumination is very striking. Especially is this the case with yellow-green, whose complementary is between red-violet and violet-red. For ordinary daylight, 122° yellow-green were required, as compared with 53°, when 50 tissues controlled the illumination. In blue-green and green-blue (Equations XI and XII), the steps of degrees are less marked.

Again, for violet-blue, blue-violet, violet, red-violet, and violet-red the regular increase under weak illumination is noticeable.

In Equation XIII (for blue), we find what seems at first sight a somewhat notable exception. Here the complementary is between yellow and green-yellow, and in this case a slight increase in the blue was required. There was a somewhat larger variation in the results of the different observations in this case, but the true explanation is more likely to be found by comparing with Figure 1, where blue appears as the second maximum of the curve. As the blue of the Milton-Bradley system inclines slightly to the violet, this apparent exception is probably no exception at all.

The following Table will show the increase or decrease in degrees for each colour, between illumination by ordinary daylight and under the lowest intensity where colour is at all observable:

TABLE XLIV.

Behaviour of the Colours in Decrease of Intensity.

Equation for	Colour disappears beyond	Minimum change in degrees.		Complementary between
		Increase.	Decrease.	
R.	50 Tissues	19 = 9%	....	B.G. and G.B.
O.R.	50 "	42 = 30%	....	B.G. " G.B.
R.O.	40 "	53 = 44%	....	B.G. " G.B.
O.	50 "	20 = 20%	....	B.G. " G.B.
Y.O.	40 "	11 = 11%	....	B.G. " G.B.
O.Y.	40 "	16 = 13%	....	B.G. " G.B.
Y.	50 "	12 = 8%	....	G.B. " B.
G.Y.	40 "	....	40 = 27%	B.V. " V.
Y.G.	50 "	....	69 = 57%	R.V. " V.R.
G.	50 "	....	4 = 3%	R.V. " V.R.
B.G.	50 "	....	23 = 17%	V.R. " R.
G.B.	50 "	....	15 = 6%	O.Y. " Y.
B.	50 "	21 = 11%	....	Y. " G.Y.
V.B.	50 "	19 = 10%	....	Y. " G.Y.
B.V.	50 "	25 = 13%	....	Y. " G.Y.
V.	60 "	46 = 20%	....	G.Y. " Y.G.
R.V.	50 "	47 = 21%	....	G.Y. " Y.G.
V.R.	50 "	32 = 14%	....	G. " B.G.

It is to be observed that the Equations showing the greatest variations under these different intensities are those involving green-yellow or yellow-green: but this is evidently because the complementaries lie in that part of the colour circle easily affected by change in the illumination. This, too, would account for the large variation in Equation III. The smallest variation is found in No. X, and it is to be noticed that the complementary qualities in this case are those found in those parts of the colour circle where the maximum saturations are about of equal intensities.

The following Table (XLV) will give a similar comparison of the variations in the black and white discs. Here, again, it will be noticed that the greatest changes are called for in those Equations involving green-yellow and yellow-green, and in each such instance there is a decrease of the white. Strangely enough, the smallest variation is again found in Equation X. Usually where one of the complementaries is in the vicinity of the yellow quality a decrease is demanded in the degrees of white. Otherwise, the variation is not very decided. In some cases the increase or decrease when the illumination was controlled by 20 tissues was much greater than when under a more feeble illumination. This occurred usually in the Equations where blue-green, green-blue, green-yellow or yellow-green is found. As the colour-quality of relatively greater intensity under feeble illumination required an increase, more degrees of white were necessary. Otherwise, a decrease was steadily observable.

TABLE XLV.

Equation for	Color disappears beyond	Maximum change in white.		Complementary between
		Increase	Decrease	
R.	50 Tissues	3 = 4%	....	B.G. and G.B.
O.R.	50 "	2 = 2%	....	B.G. " G.B.
R.O.	40 "	14 = 15%	....	B.G. " G.B.
O.	50 "	....	20 = 17%	B.G. " G.B.
Y.O.	40 "	....	12 = 12%	B.G. " G.B.
O.Y.	40 "	11 = 8%	....	B.G. " G.B.
Y.	50 "	....	3 = 2%	G.B. " B.
G.Y.	40 "	....	21½ = 16%	B.V. " V.
Y.G.	50 "	...	38 = 28%	R.V. " V.R.
G.	50 "	....	1 = 1%	R.V. " V.R.
B.G.	50 "	10 = 12%	....	V.R. " R.
G.B.	50 "	10 = 7%	....	O.Y. " Y.
B.	50 "	....	16 = 10%	Y. " G.Y.
V.B.	50 "	....	6 = 5%	Y. " G.Y.
B.V.	50 "	....	9 = 7%	Y. " G.Y.
V.	60 "	....	27 = 24%	G.Y. " Y.G.
R.V.	50 "	....	30 = 22%	G.Y. " Y.G.
V.R.	50 "	....	13 = 17%	G. " B.G.

If we seek an explanation of these phenomena it will be found in the fact that every colour sensation has as two of its attributes brightness and saturation. Of these two attributes saturation is peculiar to chromatic sensations, while the brightness quality belongs to both chromatic and achromatic sensations. As we have seen, the grade of brightness most favourable for the saturation of a colour is not the same for all, but varies widely from red to green-blue. If then, we vary the amount of light in ascertaining the complementary relations, the proportions of the physical stimuli must be varied to obtain colourless light, unless the grade of brightness most favourable to saturation be alike, or nearly so, in the case of each colour involved.

V.

CASES OF ANOMALOUS COMPLEMENTARISM

For the normal eye, complementarism remains more or less the same. It is true that, according to Purkinje's phenomenon, the qualities are dependent on the intensity, but complementarism concerns, as we have already seen, not the qualities which we say are there, but those which we actually see under the varying conditions of colour sensation. Similarly, contrast and after-images may have a great influence, but the character of complementarism is only apparently changed, i.e., in so far as it concerns the colours which we attribute to objects, not those which we actually see.

But there is a real source of anomaly in certain cases of colour-blindness. To take as an example the case of monocular colour-blindness investigated by Dr. Kirschmann in the Leipzig laboratory and described as No. 5 in his article, "Beiträge zum Kenntnisse der Farbenblindheit,"* we have there an instance in which for the one eye blue and red were the only elements in the colour system, and acted towards each other like the ordinary complementary pairs. While the left eye was quite normal for colour, the right eye could distinguish only the red and the blue, all the other colours being seen as variations in saturation of one of these two. When careful after-image tests were made with spectral colours, it was found that each spectral colour seen as red left a blue negative after-image and *vice versa*. This condition was all the more remarkable, not only because the left eye was perfectly normal in its appreciation of colours, but because the colour-blind eye was no less normal in its appreciation of the red and the blue, which acted as complementaries.

Similar anomalies with regard to complementarism probably exist in most cases of dichromasy, though they can be detected with certainty only in a case like the above mentioned, where the deviation is confined to one eye. It is easy to show that the complementary pairs of a dichromate are not the same as those of the normal, but there is no way of ascertaining how the dichromate sees them.

* Philos. Studien, Vol. VIII, p. 197.

Apart from objections that have already been raised to the Young-Helmholtz theory, it is plain that if white light is composed of red, green, and a bluish violet, it is altogether inexplicable how the colour-blind eye, in the first of the above cases, could see colourless light at all, having sensibility for only two of the three. Moreover, this same case is just as impossible to explain by the theory of Hering. If red is a sensation which arises from the destruction of a certain kind of visual substance, and blue a sensation arising from the construction of a totally different kind of visual substance, we cannot explain how this colour-blind eye could long continue to have sensibility for more than blue alone. The red substance could never be made up by the construction of the blue, and evidently must become exhausted.

Moreover it is curious indeed that there is a disturbance of the ordinary complementary relationships of the various members of the colour system when the colour surfaces are reduced to small visual angles. This has been discovered by the investigations of Lane* in the University of Toronto Laboratory. His results also show that coloured grounds do not seem to lower the space-thresholds of their ordinary complementaries so much as they do that of some other colours, such as red and blue. On the red ground almost all the colours appear first as blue, and on blue nearly all appear first as red, including even the complementaries themselves of the coloured grounds. "It thus appears," he says, "that for small angular sizes of coloured surfaces there is a disturbance of ordinary complementary relations, and that for red and blue grounds at small visual angles a condition of things obt[illegible]s which is somewhat similar to that present in the colour-blind eye of Professor A. [i.e., as instanced above]. The coincidence is not quite complete, because there is not absolute failure to appreciate other colour qualities besides red and blue. I would enunciate our conclusions on this question in the following way: On red and blue grounds, below the limits of the characteristic space thresholds of blue and red respectively, there is a lack of ability in the normal eye to make

* Lane, *Space-Threshold of Colours and its dependence on Contrast Phenomena.* (Univ. of Toronto Studies: Psychol. Series, Vol. I, p. 53 *et seq.*)

definite discriminations of the other spectral colour tones, and a tendency to confuse them with either red or blue. Thus, in a limited sphere, embracing only small angular sizes, are practically reproduced the conditions of colour sensibility exhibited by the colour-blind eye of Professor A., which form an antagonistic colour system of one dimension, founded on the two qualities, red and blue." It is easily seen that the above peculiarities in the complementary relations present formidable difficulties for any component theories, be it that of Helmholtz or that of Hering, or any of their more modern modifications.

VI.

COMPLEMENTARISM IN REGARD TO THE OTHER SENSES

If we enlarge our discussion so as to include the inquiry into complementarism in the other senses, we at once enter an immense field in which very little has been done. In the sense of hearing, we observe that the system of simple tone sensations is a continuity of one dimension. The quality of a single simple tone is called its pitch. The one-dimensional character of this system reveals itself in the fact that, starting with a given pitch, we can vary the quality only in two opposite directions. We speak of the change in one of these directions as raising the pitch, while change in the other direction we call lowering the pitch: thus making the difference greater all the time and never getting at a complementary of the original. But in our actual experience, such simple sensations of tone are never presented alone. They are always united with other tone sensations, and with accompanying noises. In all this series, however, there is nothing akin to the neutralization of one such tone quality by another. Likewise, in the sense of touch, we find nothing analogous to this phenomenon of complementarism. Sensations of pressure form a system which reveals no two in a complementary relation. This does not apply to the so-called kinaesthetic sense, however, for here we find that there is an antagonism of the action of the muscles in such a way that almost every movement is regulated by a pair of antagonists. Nevertheless this anatomical or physical antagonism is not represented in sensation. In the sense of sight, complementarism (i.e., antagonism) and contrast are very closely allied, whilst in other senses we find antagonism without contrast and *vice versa*. We must conclude, therefore, that this alliance is not a necessary one. Thus we find psychically nothing of complementarism in the haptic and kinaesthetic senses, although we encounter there an abundance of contrast phenomena.

It is only when we come to the sense of temperature that we see a striking parallel to this phenomenon. In this case there are only two qualities, but they are indeed antagonistic and complementary. These two are not as the sensations of light and dark, which do not neutralize each other, but give a series of sensations of grey. Rather, these qualities stand in the relation of opposites or contrasted sensations, like a pair of complementary colours. "Heat and cold exclude each other, because, under the conditions of their rise, the only possibilities for a given cutaneous region are either a sensation of heat or one of cold, or else an absence of both. When one of these sensations passes continuously into the other, the change regularly takes place in such a way that either the sensation of heat gradually disappears and a continuously increasing sensation of cold arises, or, conversely, the sensation of cold disappears, and that of heat gradually arises. Then, too, elementary feelings of opposite character are connected with heat and cold, the point where both sensations are absent corresponding to their indifference zone."* Titchener presents a somewhat different view. He says: "We are apt to think of temperatures physically as degrees of one and the same quality. Warmth and cold are, psychologically, qualities of different senses, proceeding from different sense-organs. If they differed merely in degree they would cancel each other when mixed, as positive and negative numbers cancel each other when summed; they could not possibly fuse together to produce a third conscious quality. Heat (warmth × cold) may be compared, psychologically, to colour (colour proper × brightness), or taste (taste proper × smell), or the

* Wundt, *Outlines of Psychology* (2nd Edition), p. 54.

note of a musical instrument (fusion of a number of tones and noise). All alike are illustrations of 'fusion.'"* The fact of the adaptation of the nerve to the momentary temperature of the skin seems hardly to be in harmony with the existence of special apparatus for the two qualities of the temperature sense. But, apart from the difficulty connected with the theory of heat and cold spots as the peculiar terminal organs, we may well ask what that "third conscious quality" is. If any considerable area of the skin receive such stimulation, we have either a sensation of heat or one of cold, and we know that these temperature sensations do pass into each other through a point of indifference. Since we find no third quality we are justified in believing that they do cancel one another.

In the sense of taste, we find that complementarism has a wide range, for a too prominent taste can be neutralized by others. As Brücke remarks: "Experience teaches us that certain sensations of taste do compensate one another, although the chemical properties of the stimuli do not compensate one another."† Kiesow‡ has followed up this investigation experimentally with a view to answering two questions: (1) Do qualitative changes occur with mixtures of the substances of taste? (2) Is this phenomenon in the sense of taste to be regarded as completely analogous to the complementary relations of the so-called colour-opposites? Four primary qualities are to be distinguished, he concludes; but between these primary qualities there are many possible transitional tastes which are to be regarded as mixed sensations. The primary qualities are salt, sour, sweet, and bitter. Some investigators have been inclined to include metallic and alkaline in this list, but the former shows an unmistakable relationship to sour, and the latter to the saline taste, so that these two are probably mixed sensations. The qualities, salt and sweet, are opposite, and when these are united in proper intensities, the result is a neutral mixed sensation (which Kiesow describes as "soapy," and

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* Titchener, *Experimental Psychology*, p. 91.

† *Vorlesungen über Physiologie*, Bd. II, p. 247.

‡ Kiesow, *Beiträge zur physiologischen Psychologie des Geschmackssinnes.* (Philosophische Studien, Vol. XII, p. 255). See also Philos. Studien, Vols. IX and X.

Wundt as "insipid"). No combination was found by Kiesow which he could describe definitely as the indifference point, yet the qualities do weaken one another, and the principle of compensation is plainly observable. "The system of taste sensations is, accordingly, in all probability to be regarded as a two-dimen-

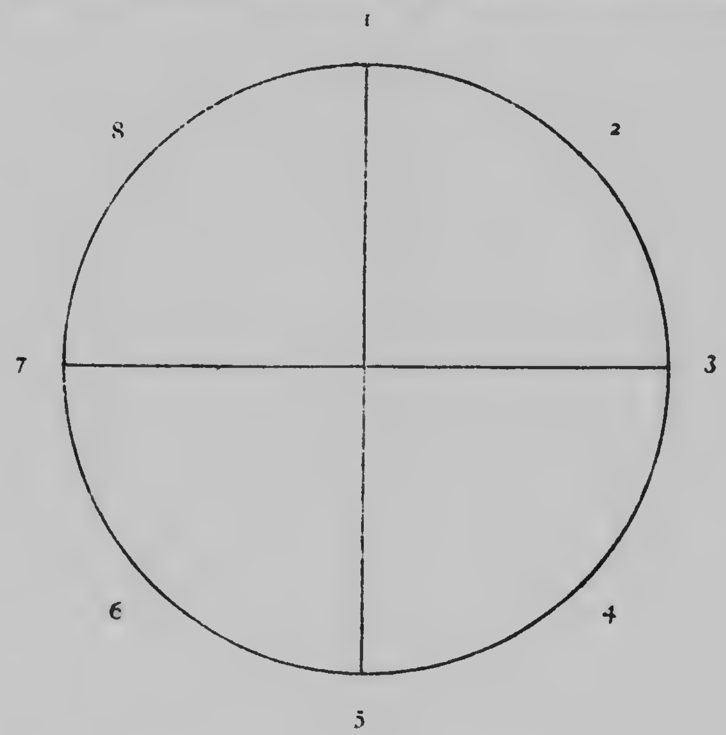

FIG. 16.

1. Salt.
2. Salt-Sour.
3. Sour.
4. Sweet-Sour.
5. Sweet.
6. Bitter-Sweet.
7. Bitter.
8. Bitter-Salt.

sional continuity, which may be geometrically represented by a circular surface on the circumference of which the four primary and their intermediate qualities are arranged, while the neutral mixed sensation is in the middle, and the other transitional taste qualities are on the surface between this middlepoint and the saturated qualities on the circumference."* This would be graphically represented by Figure 16.

There are certain analogies, then, between the sense of taste and the higher sense of sight. The resultant fusion of tastes is not equal to that of colours, and consequently shows relations which need separate investigation; but the phenomenon of the complementarism of colours finds its counterpart in this neutralization of certain tastes by others which stand apparently in a complementary relation.

The sense of smell stands in a close relation to that of taste, and Zwaardemaker† has endeavored to establish a complete analogy between the two. He holds that two smells can be mixed in such proportions that each may be made weaker or stronger, and that they may be graded so that the point of complete indifference is obtained. He finds this to be the case, whether the stimuli are directed to one or to both nostrils. If the stimuli are balanced, there is no perception of smell, or else a weak and undecided impression, which can only be noticed by very close attention, and which is similar to neither component. Therefore, he maintains that in the sense of smell the principle of compensation obtains. This, however, has not been confirmed by other investigators, who regard it as doubtful. The most we can say as yet is that sensations of smell form a complex system of many different qualities whose arrangement is not definitely known; but it is probable that the system is a continuity of many dimensions. Wundt‡ expresses his view as follows: "It has been observed that many odours neutralize each other, so far as the sensation is concerned, when they are mixed in the proper intensities. This is true not only of substances that neutralize each other chemically, as acetic acid and ammonia; but also of others, such as caoutchouc and wax, or tolu-balsam, which do not act on each other chemically outside of the olfactory cells. Since this neutralization takes place when the two stimuli act on

* Wundt, *Outlines of Psychology*, p. 61.

† *Die Physiologie des Geruchs*, p. 165 *et seq.*

‡ Wundt, *Outlines of Psychology* (2nd Edition), p. 60.

entirely different olfactory surfaces, one on the right and the other on the left mucous membrane of the nose, it is probable that we are dealing, not with phenomena analogous to those exhibited by complementary colours, but with a reciprocal central inhibition of sensations."

It is customary to classify the senses into mechanical and chemical senses. In smell and taste we have external chemical agencies; in sight we have light as the cause of chemical disintegrations in the substances of the retina. These are distinguished from the mechanical senses of pressure and sound, while it is as yet impossible to say definitely to which class the sense of temperature belongs. From the standpoint of complementarism this classification seems to be perfectly justifiable; for where a chemical function is associated with sensation there is the probability of a play of antagonistic processes, but we cannot expect the same phenomena from the neutralization of a mechanical function. Complementarism, then, is not to be identified with contrast; for, while the latter is found in all the senses, the former is limited to a few.

VII.

CONCLUSION

The attempt to explain complementarism from the physicist's standpoint fails, as we have seen, because there is no fixed relation of wave-length which could be claimed as a physical analogon. Thus, many have sought the explanation in the processes of the retina. The Young-Helmholtz theory is a very inadequate attempt in this direction, seeing that it was made primarily to explain the facts of colour mixture. On the other hand, Hering's theory was formulated mainly to explain the facts of complementarism; but it has the fault of all component theories, and does not explain the cases of abnormal complementaries at all, nor does it account for the influence of contrast.

A very curious theory of this class is that advanced by Ebbinghaus, it being a modification of the Hering theory. In the Hering theory complementarism is rather plausibly explained as the outcome of antagonistic processes; by Ebbinghaus the processes are not regarded as antagonistic. Instead of being an assimilation and a dissimilation, they are both states of decomposition, i.e., a certain degree of decomposition causes the one colour, a higher degree of decomposition causes the antagonist. There remains, of course, the same mystery as in the sense of temperature, where you have to admit that a certain degree of physical heat causes the sensation of cold and a higher degree causes the opposite sensation, heat. On the one side we have the quantitatively purely one-dimensional system, on the other side the bipolar or antagonistic system; hence nothing is explained.

G. E. Müller* in his new colour theory seems also to treat complementarism completely from the physiological side. Only the outer excitations are bound to one another in pairs of antagonistic processes, whilst the more centrally located inner excitations are independent. All these theories, even if they were correct, would (as Kirschmann states in *Normale und anomale Farbensysteme*) treat at best the complementarism or antagonism of retinal or cerebral processes, but do not deal with the sense qualities at all.

The only theory which does not make "our knowledge of the physical processes the 'Prokrustes Bed' for the analysis of the psychical facts" is Wundt's theory (Stufen-Theorie) of colour.† He points out that a careful observation of the whole system of light and colour sensations leads us to expect a different relation between the psychological facts and the physical or physiological processes from that occurring, for example, in the auditory sense. In the latter, the principle of parallelism holds largely both for the physical and the physiological processes of stimulation. Thus a simple sensation has its corresponding simple form of sound vibration, and a combination of these the corresponding compound form. The quality varies with the form of the vibration, and the intensity with the amplitude of

* *Zur Psychophysik der Gesichtsempfindungen.* (Zeitschrift für Psychologie und Physiologie der Sinnesorgane, Vol. XIV, p. 106).

† *Physiologische Psychologie*, Vol. II, pp. 252 *et seq.* See also his *Outlines of Psychology*, pp. 78 *et seq.*

the wave-length. But in the system of light and colour sensations, we find somewhat different phenomena. While the simple sensations correspond to vibrations of certain wave-lengths, the quality varying continuously with the wave-length and with the rate of vibration, yet we observe that red, which corresponds to the longest and slowest waves, and violet, which corresponds to the shortest and most rapid, are yet approaching one another again in quality. Not only so, but every change in the amplitude of the vibrations corresponds to a change in both the quality and the intensity of the sensation (Purkinje's phenomenon, etc.). Furthermore, every light sensation is psychically simple, even though it responds to many kinds of vibrations. It is therefore apparent that light which is physically simple may produce not only chromatic but also achromatic sensations. From the quality of the achromatic sensation, we cannot say whether it is produced by a change in the amplitude of the vibrations or through a mixture of simple vibrations of different wave-lengths. Thus, a sensation of pure brightness of a given intensity may result not only from a mixture of all the rates of vibration in solar light, but it may also result when only two kinds of light waves are mixed in proper proportions, as we have seen in the phenomenon of complementarism. The kinds of light necessary thus to produce a sensation of pure brightness are those which correspond to sensations subjectively the most different. Then, too, each colour sensation may have more than one source, for if we mix two objective colours nearer than the complementaries in the colour-circle, we obtain not a white but an intermediate colour-quality.

In view of these phenomena, it is clear that no simple relation can exist between the physical stimuli and light sensation, but it is possible that such a relation may exist between the physiological processes and sensation. As different kinds of physical light produce like chemical changes, the same sensation may result from various kinds of objective light. Therefore Wundt pre-supposes in the retina two substances, chromatic and achromatic, in each of which a light stimulation sets up an excitation. In the former, this is a somewhat periodic function of wave-length; in the latter, it depends upon the relative intensity of the wave-length. The intensity of the light also affects the two differently. Thus the achromatic begins at a low degree of stimulus intensity and increases continuously with it; but the chromatic is greatest at moderate intensities of stimulus. Wundt* says:

"If we take the principle of parallelism between sensation and physical stimulation as the basis of our suppositions in regard to the processes that occur in the retina, we may conclude that the photochemical processes corresponding to chromatic and achromatic sensations are relatively independent of each other in a way analogous to that in which the corresponding sensations are relatively independent Two facts, one belonging to the subjective sensational system, the other to the objective phenomena of colour-mixing, can be very naturally explained on this basis. The first is the fact that every colour sensation tends to pass into one of pure brightness as the grade of its brightness decreases or increases. The fact is most simply interpreted on the assumption that every colour stimulation is made up of two physiological components, one corresponding to the chromatic, the other to the achromatic stimulation. . . . The second fact is that there are complementary colours. This fact is more easily understood when we assume that opposite colours, which are subjectively the greatest possible differences in sensation, depend upon objective photochemical processes that neutralize each other. The fact that as a result of this neutralization, an achromatic stimulation arises is very readily explained by the pre-supposition that such an achromatic stimulation accompanies every chromatic stimulation from the first, and is, therefore, all that is left when antagonistic chromatic stimulations counteract each other."

It must be remembered that, according to Wundt's theory, we should suppose that the retinal or cerebral substance for the achromatic excitation is of a comparatively simple chemical nature; whilst the chromatic substance (i.e., the substance whose decomposition corresponds to the colour sensations) must be of the nature of a very complex chemical compound. Applying this same principle of psycho-physical parallelism to the chromatic stimulation itself, we must suppose that the complementary colours, which correspond to largest differences in stimulation, really are associated with processes which neutralize each other. As such neutralization can only occur when they are somewhat opposite in character, and as each sensation has a complementary quality, there is probably a complementary process for each stage in this chemical manifoldness of colour stimulation. This chemical process, as mentioned above, must occur in a very complex chemical molecule which can be

* *Outlines of Psychology*, p. 79.

attacked by decomposing influences in as many different ways as we can distinguish colour qualities. The circle of colour sensations, then, has in all probability a corresponding circle of chemical processes, in which each one has its neutralizing opposite. In this event, the return of the colour-circle to its beginning finds a corresponding physiological parallel in the return of the chemical processes to similar forms.

The adherents of the component theories take objection to the complex nature of the chemical compound constituting Wundt's chromatic substance. They forget that simplicity is only a principle of interpretation, and not a principle which is inherent in the facts. The higher the development of an organism and the more sensible it is to the various stimulations, the more complex is the chemical constitution of its parts. This is something which organic and physiological chemistry has clearly demonstrated; and we should not object to the complexity simply because we do not completely comprehend it. In fact, the more we try to understand the mystery of the connection between the vast manifoldness of the physical and physiological processes and that one unity and continuity, the mind, the greater is the complexity which confronts us. And if we would not end in logical inconsistencies, we must assume, as Wundt did in his Physiology, that the whole human body, regarded from a chemical standpoint, is one very complex molecule.