I can conclude on the basis of the above reported data that the dark green colour of the leaves of the euploid forms in comparison to their original ones is due to the larger amount of chlorophyll per leaf surface unit. Leaves of polyploid plants are thicker, the thickness being due to the larger dimensions of the leaf cells. Larger cells have larger number of chloroplasts. These factors condition the larger amount of chlorophyll in the polyploid plants. The size of the chloroplasts is not responsible for the larger amount of chlorophyll in the polyploids since the euploid chromosome alterations do not lead to an increase in size of the chloroplasts, the latter being highly autonomous in respect to eupolyploid chromosome alterations.

It seems logical to postulate that the polyploid forms, having larger amount of chlorophyll, should have a greater assimilation ability per surface unit and should produce a greater amount of carbohydrates per surface unit.

An Interpretation of the Benham Colour Phenomena in Terms of the Hysteresial Augmentation Theory of Professor Burridge.

By P. S. Naidu, *Annamalai University.*

THE chromatic responses elicited by simple black and white stimuli have been studied by Fechner, Helmholtz,[1] Nicholls,[2] Bidwell[3] and others. When a disc containing black and white sectors is revolved rapidly blue and yellow rings develop very quickly. This development of coloured rings is a remarkable phenomenon in itself. But the most striking development of colours occurs in connection with the manipulation of, what is popularly known as, the Benham's Top. The striking behaviour of this revolving disc has been studied by Bidwell,[4] V. Kries,[5] Pieron[6] and Parsons,[7] and partial explanations have been given by all of them, especially by Pieron and Parsons. V. Kries admits that 'these phenomena are as yet only partially understood, and cannot be classified or positively explained'. Pieron and Parsons attempt to explain the generation of colour sensations by simple black and white stimuli as due to induction by certain spatio-temporal patterns. The latter says, 'When light falls upon the retina the luminous sensation rises rapidly and falls gradually ....It is seen that the rapidity and amount of rise of sensation varies with the intensity of the stimulus, and also with the wave-lengths of monochromatic lights. The maximum is greatest with blue, least with green, and intermediate with red. It is probable that Fechner's colours seen with rotating black and white sectors, and the colours seen with Benham's Top are due to this cause.'[8]

Attempts have been made to explain the generation of colours by the well-known phenomena of contrast, successive and simultaneous. But all such explanations have been disapproved by Pieron and Parsons who show that the colours develop in monochromatic light.[9] We shall refer to this point again. Neither the 'contrast' explanation nor the 'spatio-temporal' explanation is satisfying; and so we are not surprised to find Parsons striking a disconsolate note when he concludes his discussions with the following remarks: 'Pieron's explanation of this fact is obscure and unsatisfactory. It is more probable that the true explanation depends upon reciprocal induction, but that theory also involves difficulties in time relations.'[10]

Our experiment with the Benham's Top yielded very interesting results. Instead of the usual cardboard disc, we used a circular glass disc, painted with Indian ink, as shown in Fig. 1. This was backed by a circular white board of the same diameter as the glass disc and mounted on a motor whose speed was regulated by the use of

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1 *Physiological Optics*, p. 215.

2 *American Journal of Science*, 1884, **28**, 243.

3 *Proc. Roy. Soc.*, 1896, **60**, 368.

4 *Curiosities of Light and Sight.*

5 Helmoltz, *Physiological Optics*, **2**. Approved by V. Kries.

6 *L' Annee Psychol.*, 1923, **23**.

7 *The Theory of Perception*, Ch. xi, pp. 89-101.

8 *Colour Vision*, p. 91.

9 Parsons, *Perception*, p. 191.

10 *Ibid.*, p. 192.

rheostats. In order to keep the lighting conditions constant we used a mercury vapour lamp (3 amps.) placed at a distance of 36″ from the motor. The mercury lamp

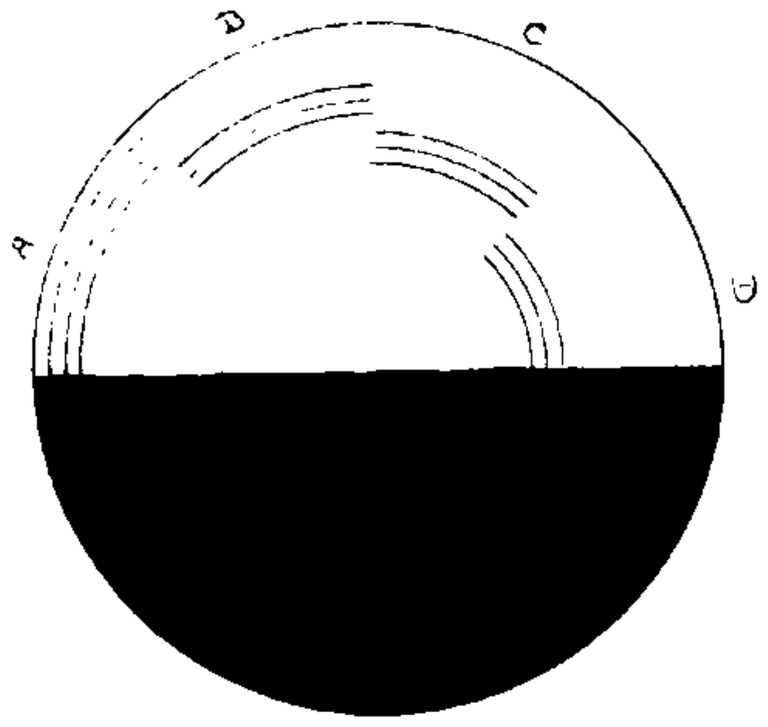

FIG. 1.

Benham's Disc.

was enclosed in a light tight box with an oblong aperture in front, covered by a milk-white glass slide, through which alone light was admitted to the revolving disc. Observations were made in a dark room through a small telescope mounted on a retort stand. Our object in using the telescope was to make it possible for us to observe only one particular set of arcs, cutting out the others, so that any influence of the latter could be eliminated. It must be mentioned at the same time that the telescope did not stand in our way when we wanted to look at the entire disc with the unaided eyes. Our observations are recorded in Tables I and II. As the results were the same when light was reflected from and transmitted through the disc, we have recorded here only one set of results. It may be noted here that the replacement of the glass disc by the usual cardboard disc makes no difference to the results.

Parsons rejects the explanations based on contrast mainly on the ground that the colours are seen even when monochromatic light is used. But we had very great difficulty in securing spectroscopically pure monochromatic sources of illumination. Even with the so-called chemical filters of light, the spectroscope revealed a wide range of colours; and with such ordinary sources of monochromatic light as the sodium flame, practically the entire spectral band is visible. It is almost impossible to get a source of pure monochromatic light (unless the spectrum itself is used as the source). The same investigator points out that 'the colours are seen only on the fine lines or on the edges of broader lines if such be used—never on the white surface'.[11] We found, on the other hand, that not only broad lines, but wide bands were completely coloured. Moreover, the white spaces acquired distinct hues—pink or green —under certain conditions.

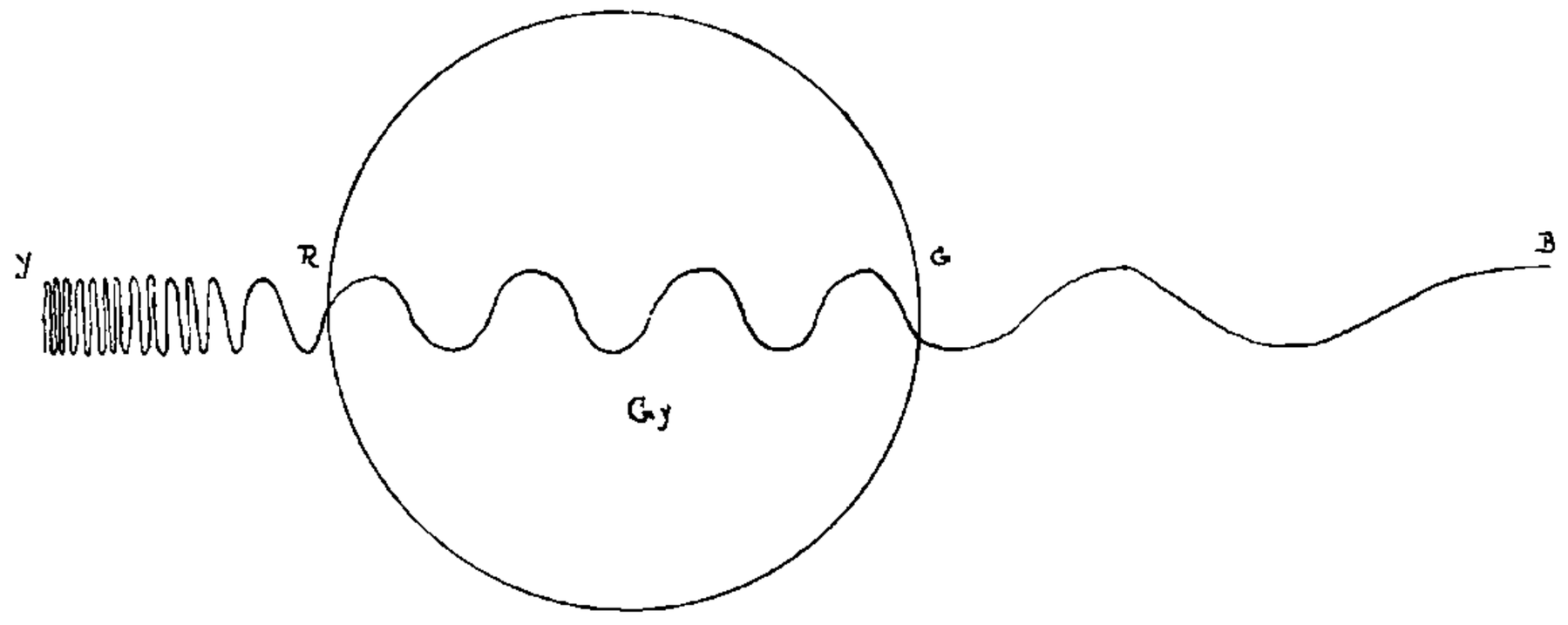

FIG. 2.

Schematic representation of the Hysteresial Hypothesis of Colour Sensation.

Augmentation. *Y*–Yellow, *R*–Red. *Gy*-Grey.

Mediated by the basic rhythm of cells. Damping. *G*–Green, *B*–Blue.

The "spatio-temporal pattern" explanation of Pieron is admitted to be the most satisfactory one advanced so far. But in his

[11] Parsons, *Perception*, p. 192.

*Colour Sensations elicited by the Benham Disc with Four Sectors.**

TABLE I.

Speed of rotation (in secs.)	A	B	C	D	Direction of rotation
0·68	violet (deep)	violet (light)	olive-green	black	↘
0·44	violet	violet	green	blue-black ?	↘
0·40	do.	olive-green	green	blue	↘
0·28	do.	do.	do.	do.	↘
	(green most pronounced—inter-spaces green)				
0·21	reddish	green	green	violet	↘

TABLE II.

Speed of rotation (in secs.)	A	B	C	D	Direction of rotation
0·67	black	violet	violet	violet	↙
0·44	do.	olive-green	do.	do.	↙
0·40	do.	green	olive-green	do.	↙
0·29	blue	do.	do.	do.	↙
0·23	violet	do.	green	black & red ?	↙

* The observations were made by the author and by another colleague experienced in advanced spectroscopic research work Mr. N. S. Subba Rao, M.A., Lecturer in Physics, Annamalai University. Neither the author nor Mr. Subba Rao was aware of the Burridge theory when the experiment was conducted.

schematic diagram to illustrate the development of various colours in the different sectors, Pieron has recourse to the tri-colour theory.[12] This theory, we know, is based on objective colour mixtures, but has no foundation in the physiological structure of the retina. All the cones have the same structure, and so have all the rods. Edridge-Green[13] has shown that the function of the rods is to manufacture the visual purple and spread it in the fluid that bathes the cones. We are, therefore, in a quandry if we rely on any one of these multi-chromatic theories. The most satisfactory procedure is to *discard boldly all of them, and seek for a theory which will account for all colour experiences on a* Monistic *basis.* Such a monistic theory is offered to us, for the first time in the history of psychophysiology, by Professor Burridge.[14]

The colour theories propounded so far have failed, because they have unwittingly started with the assumption that the retinal end-organs are inert structures roused to activity by light stimuli—an assumption which is not true to fact. This extraordinary assumption is the result of assuming that the living cell behaves in exactly the same manner as the muscle-nerve preparation on which the physiologist is wont to experiment with electrical stimuli. Professor Burridge says, 'The action of light on retinal end organs, is precisely that of rhythmical structures, though the due appreciation of this necessarily waited on a further knowledge of the latter's properties.... For there is producible in such structures a

[12] Parsons, *Perception*, Figs. 44–48.

[13] Edridge-Green, *Physiology of Vision.*

[14] Burridge, *Excitability, a Cardiac Study.*

specific type of augmentation, the hysteresial augmentation, of the efforts of rhythmically active retinal end-organs. There is no need for any further special hypothesis to explain the phenomena actually found.' [15]

Every cell in the living organism has a rhythmic activity of its own. The hypothesis of quiescence implicit in current physiological theories is false. The retinal end-organs have a rhythm of their own. The effect of light stimuli is either to augment or damp this inherent rhythm. Augmentation or damping may affect either one or both phases of a rhythmical activity. It may affect the amplitude or the frequency or both. In the former case brightness sensations are mediated, and colour sensation in the latter. Yellow and red are results of augmentation, green, and blue of damping, yellow and blue marking the extreme limits in either case. Grey is the fundamental retinal colour corresponding to the fundamental retinal rhythmic rate. Such in brief, is Professor Burridge's theory so far as it affects our problem.

The Benham phenomenon, which defies explanation on every other theory, lends itself to easy and simple explanation on this theory. When the disc is rotated black and white stimuli alternate in certain given proportions. The result of this alternation is either to augment the inherent rhythm of the end-organ or to damp it. The colours perceived are merely mediated by this hysteresial augmentation of the fundamental rhythm. In the case of our experiment, with the mercury vapour lamp, the result has been damping (except with the highest speed and with one set of arcs). The colours therefore range from violet to green. The damping (or augmenting) effect is due to speed variations, as the change in the direction of rotation merely changes the order of colours.

The theory is simple and true to fact. Other aspects of Professor Burridge's theory dealing with the two sources of energy, and with the nature of the interaction between these two sources have not been touched upon here. But we feel that with this new orientation in physiology many psycho-physiological problems will get solved in a very satisfactory manner.

When we compare the various theories of audition with those of vision we notice a very remarkable difference between them. In the case of the former there is no mention of different cochlear end-organs in order to account for the qualitative differences in the fundamental notes, though these differ as much among themselves as do the various colour sensations. All musical experiences are sought to be accounted for as due to the different types of response of the same kind of end-organ, whereas in the case of colour different end-organs are sought for. The reason for this is plain. The physiologist borrowed the tri-colour theory from the physicist and then attempted to twist the facts in order to make them fit with the unnatural hypothesis. What we need is complete emancipation from the misguiding influence of these multi-coloured and pluralistic theories. Professor Burridge's new physilogical psychology gives us hopes of such emancipation. We find that Benham's phenomenon is one more powerful link in the long chain of evidences adduced by the Professor in support of his new theory of hysteresial augmentation.

In conclusion, I wish to thank my colleague Mr. N. S. Subba Rao for conducting the experiment and for having made it possible for me to secure the valuable results.

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[15] Burridge, *A New Physiological Psycholgy.*
Burridge, "Colour Vision", *Scientia*, 1934, **56**, 141–151.