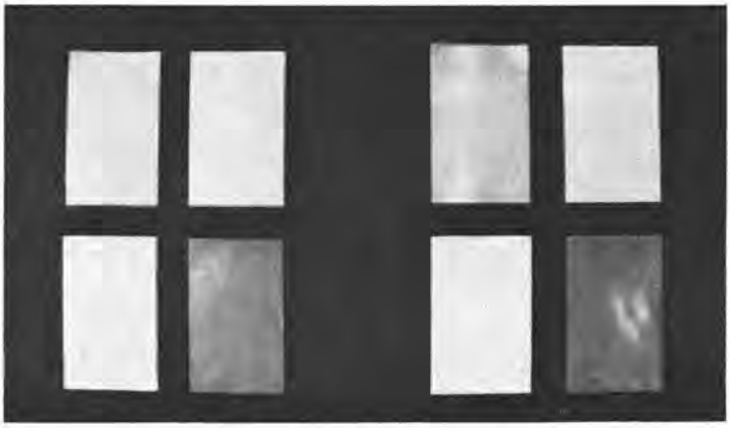

FRONTISPIECE. Stereoscopic photographs of four 3-by-5-inch color chips mounted on a black board. Viewed stereoscopically, they seem to be at different levels. Upper left is blue, upper right is green, lower left is yellow, and lower right is red.

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The Stereoscopic Effect of Color

Targets of different colors stand at different elevations on both color and black-and-white film.

(Abstract on next page)

INTRODUCTION

ABOUT 300 YEARS AGO, Sir Isaac Newton discovered the composition of light. At the same time he discovered the differences in the wave lengths or frequencies of colored light. This paper reports some limited experimentation in employing those differences stereoscopically during a study for the development of Objective Color Sensors at the U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency, Fort Belvoir, Virginia, during 1964 and 1965, financed in part with research funds from the National Aeronautics and Space Administration.[1] The experimentation was performed in order to devise a method of reporting terrain color which would not be subjective to human viewing, or variations in color photography which occur with temperature control of photographic film and developers, because all photography used was single layer emulsion, black-and-white film which is least affected by temperature variables.[1]

Experimentation in the color stereoscopic effect has been reported in a study being performed for the U. S. Army Medical Corps, by Prof. Anton Hajos.[2] During his study of chromatic vision Hajos reported that reflected light from a pair of color chips with discrete dominant wave lengths can be photographed twice with a black-and-white emulsion through an optical wedge sequentially rotated 180 degrees and yield a stereo effect caused by parallactic displacement of the color chips. This effect can be detected by viewing through a stereoscope or by measuring with a parallax bar. The displacement of the imagery is related to the spectral response from the color chips whose dominant wave lengths vary with their position in the visible spectrum. The color stereoscopic effect has also been reported by Kishto with relation to physiological optics.[3] Confirmation of the

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stereoscopic effect of color through the use of photography is reported as part of this research.

EXPERIMENTATION

In the quantitative analysis of the color stereo-effect, several experiments were performed. The first experiment was based on an extension of the work done by Hajos. A Federal Standard Color Chip, Blue, 476 mμ, with 79 per cent purity, 3×5 inches, was mounted on an easel with a Federal Standard Color Chip, Red, 615 mμ, 55 per cent purity, 3×5 inches. A Graflex, 4×5-inch-format camera equipped with an $8\frac{1}{2}$-inch-focal-length Ilex lens was mounted on a tripod and centered on the easel at a distance of 120 inches (Figure 1). The color chips were photographed through a stock Edmunds Scientific Co. 3235 Wedge, prismatic, 37×18 mm., crown glass, wedge angle 20 degrees.

One exposure was made with the base of the prism parallel to the camera lens so that the image of the chips was displaced toward the right at the negative plane; a second exposure was made after rotating the negative plane. When both photographs were processed and the images examined with a stereoscope, it was apparent that a relative parallax existed placing the red image at a lower plane than

ABSTRACT: *During a study for the development of Objective Color Sensors, experiments were performed at the U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency in order to determine the quantitative stereoscopic effect obtained from exaggerating the differential refraction of light frequencies in the visible spectrum. This exaggeration was obtained by the attachment of optical wedges to standard photographic cameras. This approach employs the physical property of the differential refraction of light frequencies in a pair of prisms to cause a visual stereo image in which the spectral elements are displayed in a relative parallax, apparent as Z-coordinates. The exposure of a group of color chips was projected through an optical wedge with the base toward the right side, then the wedge was rotated for the second exposure with the wedge base toward the left. The resulting dispersion of the spectra in opposite directions created normal and color parallax from a single (monocular) camera position.*

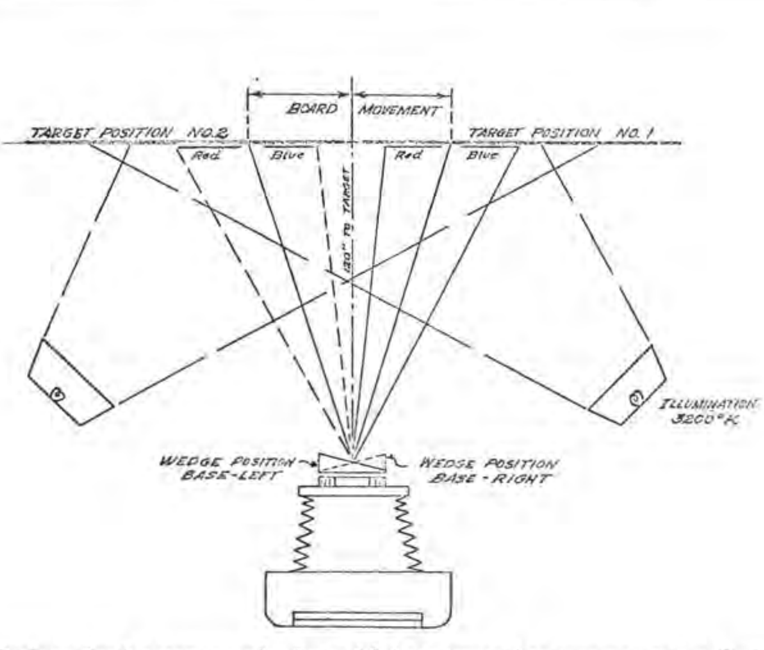

FIG. 1. Single wedge for stereoscopic effect with board moved to compensate for displacement.

FIG. 2. 3-by-5-inch color chips mounted on an easel. Red is on the left, blue on the right.

the blue image, although they were both in the same plane on the easel. The effect is analogous to the prismatic defect of the human eye[3] (Figure 2).

The experiment above was performed in a photographic studio with an artificial light source rated at 3,500 degrees Kelvin. In order to determine the persistence of this effect in natural daylight, further experiments were performed in shade with north light at approximately 4,500 degrees Kelvin. A group of four Federal Standard Color Chips, Red (615 mμ), Blue (476 mμ), Green (519 mμ), and Yellow (578 mμ) were mounted on a sheet of illustration board painted with 3M Velvet Black paint (non-reflecting). A Lucite optical wedge with a 10 degree wedge angle was designed at GIMRADA and fabricated in the Model Shop of ERDL. A Polaroid camera was used in order to check the results. The photographs were made as described in the preceding experiment. Again relative differences in parallax were noted when viewed through a stereoscope (Frontispiece).

The effect was obtained in Polaroid black-and-white as well as in Polacolor. There was an evident relative parallactic difference in all four color chips related to their wave length. A more elaborate test plan was devised based on "Plan of Test for the Determination of Relative Color Values by Parallactic Displacement," dated 3 February 1965.[4]

Eight Federal Standard 595 Color Chips ranging from 476.4 mμ to 619 mμ were mounted on a 4×4 foot board which had been painted with 3M Velvet Black non-reflecting paint (Figure 3). A flint glass wedge with a wedge angle of 9° 57′ was fabricated by the McMinn Optical Co. The wedges were mounted in holders designed at GIMRADA and fabricated by the Model Shop of ERDL. The holders were designed to rotate the wedges to predetermined angles. Exposures were made with the flint glass wedge, the Lucite wedge and combinations of both as shown in Figure 4. The photography was performed outdoors in July 1965 in full sunlight with Kelvin temperatures of approximately 5,000 degrees. Figures 5, 6, 7, and 8 reproduce the resulting photographs. The color stereo effect was discovered to persist under poor image forming conditions. Examination of Figures 9 and 10 with a stereoscope demonstrates the persistence of the effect

FIG. 3. Relative position and colors of test color chips as mounted on target board, Dimensions are in inches.

Color Chip No.	*Predominant Wave Length*	*Color*
21105	610.0 mμ/	Red
22246	596.8	Orange
23655	478.5	Yellow
24260	518.0	Green
25102	476.4	Blue
27142	508.0	Purple
24466	550 (Approx)	Light Green
27144	500 (Approx)	Light Purple

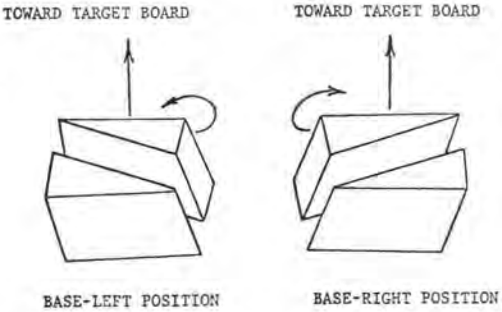

FIG. 4. Combined wedges for the stereoscopic effect. The front element is rotated to simulate variable wedge angles and to minimize deviation while maximizing refraction and dispersion.

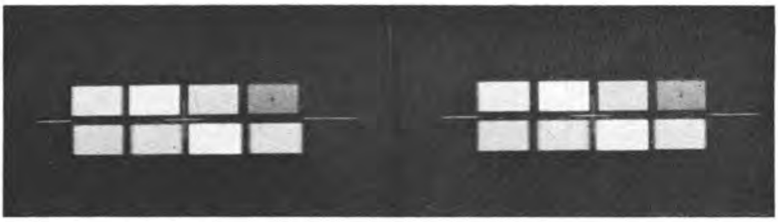

FIG. 5. Stereoscopic pair using a 10-degree Lucite wedge. Normal exposure, 8.5-inch lens, 14.8 feet to the target.

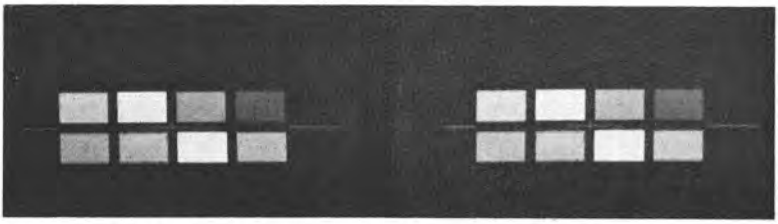

FIG. 6. Stereoscopic pair obtained with combined Lucite wedges. The front wedge is rotated 30 degrees.

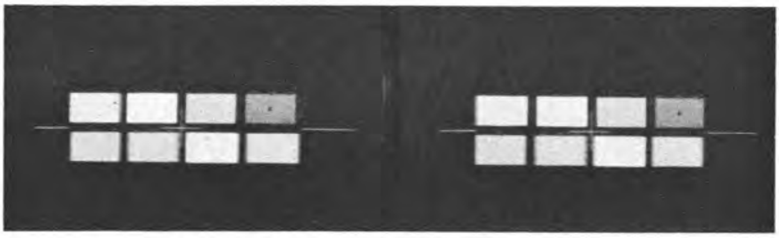

FIG. 7. Stereoscopic pair obtained with combined Lucite and flint glass elements in 180-degree opposition. 8.5-inch lens, 14.8 feet to the target.

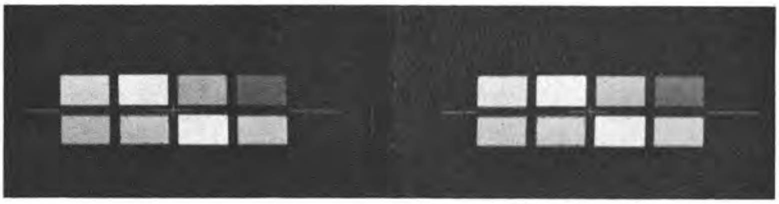

FIG. 8. Stereoscopic pair obtained in Figure 7 with combined wedges. 135-mm lens, 69.5 inches to the target.

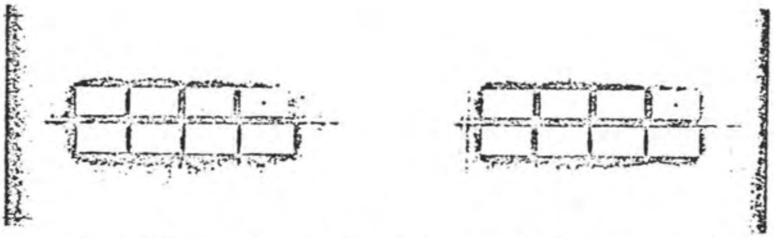

FIG. 9. A Xerox copy of Figure 7 showing how the stereoscopic effect persists under poor image. formation.

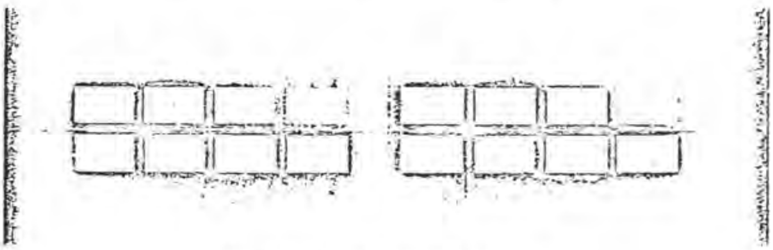

FIG. 10. A Xerox copy of Figure 8.

when the images are edge enhanced by Xerox printing.

The optical wedges were employed in a combination of the Lucite and flint glass in order to minimize geometric deviation of imagery and maximize the differential refraction of the spectral response from the imagery. Measurable parallactic displacement of the spectral components was the goal of the experiment. Camera lenses of 100 mm., 127 mm., 135 mm. and 200 mm. focal lengths were used in the field tests. The exposures were varied as much as 64 times over-exposure based on the theory that binary (black-and-white) images would have no dispersion fringes. Despite the extreme over-exposure, fringing effects interfered with precise measurements of parallax.

ANALYSIS OF RESULTS

Photography obtained through the flint glass wedge had the maximum stereo-effect from color refraction, but the dispersion of the colors also caused the imagery to suffer in resolution. Less color dispersion was produced by the Lucite wedge, consequently yielding better edge definition for the imagery. Combinations of the Lucite wedge and the flint glass wedge minimized the dispersion of colors, and aided the resolution of the images, yet the effect was too great to permit accurate measurements. Table I represents the results of measurements made by several observers who used a Zeiss stereomicrometer while viewing the imagery through a Bausch & Lomb mirror stereoscope.

All of the measurements are relative to the position of the Red Color Chip (615.0 mμ). Efforts to measure the parallax differences on a Wild Coordinatograph were not successful as the "fringing" effects caused by the color diffraction resulted in a low confidence level of measurement.

CONCLUSION

Several conclusions can be drawn from these experiments. Among them are:

- If an image is photographed through an optical wedge, a displacement occurs which is related both to the wedge angle and to the wave length of reflected light.
- The displacement of imagery is relative to the wave length of other imagery in the same scene, thus creating the stereoscopic effect of color by a relative parallactic shift.
- The displacements that can be measured as parallax are observable in both black-and-white and color photography.
- A color fringing effect is also produced by the same phenomenon that produces the parallax measurements. That is, dispersion also occurs.
- The measurements shown in Table I have limited value, because the parallax differences are so small that differentiation becomes difficult. Because of the fringing, parallax errors tend to be of the same order of magnitude as the parallaxes.
- This technique could prove to be a useful tool for making crude distinctions of color, even for color-blind observers. The photographic emul-

TABLE 1. PARALLAX MEASUREMENTS IN MILLIMETERS

	Observer 1	*Observer 2*	*Observer 3*	*Observer 4*	Δp^1	Δp^2	Δp^3	Δp^4
Red	50.820	50.940	50.805	50.850				
Orange	50.760	50.835	50.650	50.655	+.060	+.105	+.155	+.195
Yellow	50.700	50.960	50.670	50.705	+.120	−.020	+.135	+.145
Green	51.000	51.140	51.140	51.220	−.180	−.200	−.335	−.370
Blue	51.670	51.335	51.560	51.280	−.850	−.415	−.755	−.575
Purple	51.260	51.190	51.065	51.185	−.440	−.250	−.260	−.335
Lt. Green	51.140	51.185	51.055	51.220	−.320	−.245	−.250	−.370
Lt. Purple	51.540	51.470	51.560	51.600	−.720	−.530	−.755	−.750

Δp is the difference in base distance between red color-chip images and other color-chip images in the stereo model.

sion is not a necessary requirement for the system, and the difference in parallax might be measured by other sensors by recording or enhancing media.

- Further refinement of the optics and recording may well succeed in reducing the fringes to acceptable error levels.
- As a basic optical phenomenon it is considered important that the color-stereo effect be considered in the use of color photography for stereo-plotting mapping photography, and that the effect can be a significant factor in optical design and usage.

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