Color studies

unequal in crossing from one row to the next.

"The CIE has a working program to improve on this and work on other versions of formulas as well," Dr. Wyszecki says.

By learning how the human eye perceives color differences, researchers may formulate a better description of color-perception space.

Design and construction of instrumentation in the NRC color laboratories was begun in 1958. In particular, the seven-field colorimeter designed for these studies is the only instrument of its kind in the world.

On this instrument, an observer with normal color vision sees an array of six small hexagonal windows closely packed around a central window. The colors in each of the seven windows can be varied independently and widely. A difference between the color in the central window and one of the neighboring windows is initially fixed. The observer must then create five colors in the remaining five windows so that the final differences in all six radial and peripheral directions are identical and equal to the initial difference. Researchers have found that color discrimination in the eye varies with the illumination and with the color of the field surrounding the colored array. The array of seven colors from each test run represents one portion in a cross-section of the observer's color-reception space.

To build up a representation of color space "you need quite a few observers," Dr. Wyszecki explains, "and you must control the various parameters which influence their judgment. For example, the size of the colors plays a part as well as the level of light available. Also, whether you look at the colors in the dark or have a white or gray surrounding is important and has not yet been fully investigated. Obviously, the relationships are very complex."

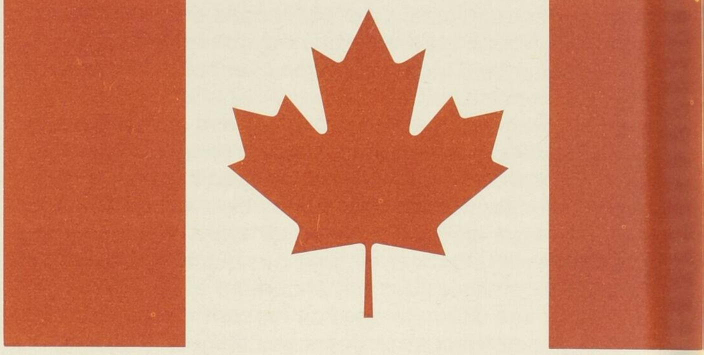
Once the color discrimination faculty of the human eye has been expressed in mathematical terms, improved color-difference meters can be built for industrial use. The language of colorimetry and, in particular, that of color-difference measurement, can then be the same for all.

"Our aim is to give industry two things," Dr. Wyszecki says. "One is the possibility of measuring any color in terms of three X, Y, Z coordinates or tristimulus values. The other concerns color differences which require a formula such as the ΔE formula which can measure the distance between two colors in a uniform color space which is transformed from the X, Y, Z space. With these tools, industry will have a complete system of colorimetry, will be able to specify a color exactly in objective terms and specify color tolerances as well."

A calibrated colorimeter can tell the manufacturer right away whether a color is on- or off-standard and by exactly how much. Eventually, interfaced with computers, colorimeters can control machinery on-line, simultaneously checking and adjusting color variations.

The research program in the Radiation Optics Section explores several other related areas. One is color-matching, where scientists test the precision of an observer's ability to match one color to another under various conditions.

The basic laws of color matching were summarized by Grassmann in 1853. One law implies that three coordinates are necessary and sufficient to specify any given color. Another law, that lights of the same color produce identical effects in mixtures regardless of their spectral composition, forms the basis of all modern colorimetry. As conceived, Grassmann's set of principles was thought to hold true over



This maple leaf will not change color with the seasons. A precise specification of the standard red color for the Canadian flag was established in 1965 by the Radiation Optics Section of what was then

the entire range of light levels. In the moderate range employed for most colorimetric purposes, these laws do hold exactly. However, under certain other conditions, they may break down.

Dr. Wyszecki says, "there are phenomena taking place inside the eye and the receptor mechanism at various stages along the pathway of the optic nerve which interfere with the simple color vision model implied in Grassmann's laws."

Since 1970, G.H. Fielder of the Radiation Optics Section has been testing the color matching abilities of observers under varying conditions on a trichromator, one of only three similar instruments in the world.

Test subjects exactly match a color adjacent to a given one by varying the intensities of three primary colors. The lights produced by these three independent intensity settings of red, green and blue add together to produce the observer's matching color.

Most color vision is studied in colored fields of either 2-degree or 10-degree size. In a 2-degree visual field, having roughly the size of a 10 cent piece at arm's length, the image is focussed directly on the fovea within the observer's eye. The fovea is a small area of the central retina having maximum color sensitivity. A dental grip, specially constructed for each subject, ensures that the same head position will be maintained between test runs and that light will enter the eye through the center of the pupil to arrive at the fovea. By increasing the size of the observed field and the level of light, scientists can test the range of validity of Grassmann's laws.

"These areas are mainly of academic interest from the point of view of basic vision research." Dr. Wyszecki explains. "But it establishes also, for practical purposes, the region within which our colorimetry holds. There are many cases where we have to look at very bright surroundings and there are situations where light is very dim. Some standard method of color specification would be desirable."

Under varying light conditions there are different receptor mechanisms in the eye. Receptor cells called rods respond to very small amounts of radiant energy (such as in moonlight) and give high sensitivity but only achromatic or neutral color perceptions of white, gray and black. On the other hand, cone cells are most sensitive at higher light levels (daylight) and provide our perception of chromatic color. However, in dim light levels or twilight vision the relative participation of