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THE COILLE EFFECT: A MANIFESTATION OF THE REVERSIBILITY OF LIGHT RAYS

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One lovely late summer afternoon a friend and I were sitting outside basking in a very large tub of hot water. The afternoon sunlight was fragmented by the branches of a tree into many parallel beams. These beams were refracted at the water surface and gave leafy patterns of sunlight on the bottom of the tub. At the edges of the patterns Coilee noticed color effects. With smug erudition I explained these as being due to the greater refraction of blue than of red light. But that wasn't what she meant. Coille had noticed a peculiarity of the color effects. Depending on where she sat, the patterns either had colored edges or did not! When she sat with the sun coming over her shoulder the patterns appeared perfectly white (or sun-yellow, rathor). When she faced the sun and looked at the same patterns from the other side of the tub they had colored edges. At first I didn't believe her. How could the color depend on where you sit? Finally I was able to overcome my prejudice and see the effect. Then I didn't believe my eyes.

How can it be that a color pattern produced by refraction can look so different depending on the angle of view and whether one is close to it or not? ¹

The explanation is straightforward, and leads to a nice demonstration of the reversibility of the paths of light rays. In Fig. 1 we see a narrow beam of white (W) light incident along path 1 to 2, striking the water surface at point 2. The blue (B) component of the white light is refracted more than the red (R) and goes from 2 to 4. Red goes from 2 to 3. The bottom of the pool is a diffused reflector. Therefore the points 3 and 4 each constitute a light source sending out light in all directions. Consider an observer whose eye is located near the point 1 and who looks at the pattern of light emitted by the sources at 3 and

4. Because of the reversibility of light rays the path of the red light from point 3 to the observer at 1 must be along path 3 to 2 to 1. Similarly blue light from 4 that gets to the observer must take path 4 to 2 to 1. Thus both red and blue return to point 1 along path 2 to 1, i.e., they enter the observer's eye traveling in the same direction along the same ray. Thus the observer sees points 3 (red) and 4 (blue) superposed on top of one another. They both appear to come from the direction of point 8. Her eye and brain now combine the color spectrum and she sees a white spot on the bottom of the pool.

Now consider what happens when she moves her head from point 1 to point 7. (The light beam is still incident along ray 1 to 2.) Suppose that the blue light from point 4 travels along path 4 to 6 to 7. What path must the red light take in going from 3 to 7? If it could go along path 3 to 6 to 7 then the blue and red beams would superpose to give a white spot. But what would demand that the red light refract more than blue at point 6, whereas we know that instead the red refracts less than the blue. Thus the red light takes a path 3 to 5 to 7. The observer at 7 therefore sees red and blue light incident from different directions, and thus sees a smeared out color spectrum on the bottom of the pool.

Thus we have explained Coille's observation.¹ In case one has a suitable pool (several feet deep with a smooth water surface) and sunlight, but no foliage to make beams, one can make sunbeams by punching holes in a large piece of cardboard and floating this on the surface of the water.

It occurs to me that I might do away with the need of a beam of sunlight. For a given water depth and given angle of incidence of a nonexistent beam of white light (1 to 2 in Fig. 1), I can calculate the

pattern of blue to green to red that would occur between points 4 and 3 on the bottom. Why not just take a piece of white material and paint on it adjacent narrow stripes of blue, green, and red, with a spacing corresponding to the calculated pattern and of such color and intensity that if superposed at the retina they will give white. Then if I put the painted pattern at points 3 to 4 and my head at point 1, I should see a single white stripe. If I put my head at point 7, or alternatively reach down and rotate the piece of material through 180 degrees, I should instead see three colored stripes.

I have not made that demonstration.

It is a pleasure to acknowledge the acute observations of Coille Hooven which were the basis of this note.

Reference

1. I have not seen what I call the Coille effect mentioned anywhere.

I searched in standard optics textbooks and in that beautiful book by M. Minnaert, Light and Colour (Dover Publications, Inc., New York, 1954).

Figure Caption

Fig. 1. A white (W) light ray which includes components blue (B) and red (R) is refracted at point 2 in going from air to water. An observer at point 1 sees a white point apparently at point 8. An observer at point 7 sees a color spectrum apparently extending between points 9 and 10. Angles of refraction have been greatly distorted for conceptual clarity.

Fig. 1

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