Gas Mixture Lens Measurements

By A. C. BECK

(Manuscript received June 15, 1964)

Different gases have different refractive indexes. If two different gases are introduced into different parts of a straight hollow tube and allowed to continue in laminar flow, they diffuse into each other slowly but remain sufficiently separated so that a refractive index gradient is maintained for some distance. It has been suggested by A. R. Hutson, G. E. Conklin, and the author that various optical components such as prisms and lenses can be obtained by using such gaseous structures. These components have very low losses and reflections, with no solid surfaces to cause matching or cleaning problems. For these reasons they may have important applications in optical communications systems.[1,2,3]

A simple structure, sketched in Fig. 1, was built to test this principle and to get some information about the performance of a gas mixture lens. A cylindrical porous-walled tube with an inside diameter of $\frac{1}{4}$ inch and an exposed length of 3 inches was mounted inside a larger phenolic cylinder with its ends blocked to form a gas reservoir. A single-mode light beam from a helium-neon gas laser oscillating at $\lambda = 0.63$ micron was collimated at a diameter of about $\frac{1}{8}$ inch with glass lenses and then sent along the axis of the porous tube through which one gas was flowing. The second gas was introduced into the tube through the porous walls. The light beam was then intercepted on a screen about 10 to 20 feet away. If there were no optical refractive effects on this beam, a spot about $\frac{1}{8}$ inch in diameter was seen at these distances, since the beam was collimated. A diverging lens increases the spot size without the beam going through a focus between the lens and the screen. A converging lens causes the beam to become smaller, go through a focus, then expand, forming a much larger spot on the screen at distances of many focal lengths. When measuring converging lenses, a Foucault knife edge cutting the beam was used to determine the focal point and thus the focal length of the lens.

With this system, diverging lenses are obtained if the gas of higher refractive index is introduced through the walls of the porous tube while the gas with the lower index flows down the tube parallel to the light beam. Conversely, sending the less refractive gas through the porous wall of the tube through which the more refractive gas and the light beam are passing gives a converging or positive lens. The reciprocal of the lens focal length in meters (often called the focusing power or con-

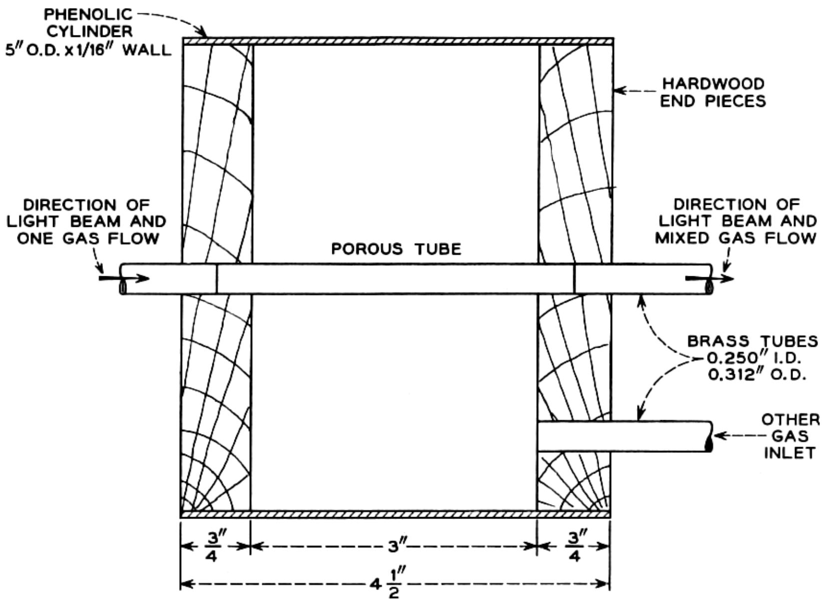

Fig. 1 — Experimental arrangement for gas mixture lens.

vergence of the lens, and usually expressed in diopters) is plotted for various gas flow rates in Figs. 2 and 3. Three different gas mixtures are shown, although other gas mixtures might have even greater focusing power. With carbon dioxide-helium and air-helium, focusing power increased with increased flow rate in the range of Fig. 2, but Fig. 3 shows that this is not the case for the carbon dioxide-air mixture in the range shown there, since focusing power at first increased, reached a maximum, then decreased as the carbon dioxide flow rate was increased. For these curves, Dextilose paper, No. 17V, was rolled up with about five thicknesses to form the porous tube. Other materials work equally well or better, porous ceramics, sintered metals, fritted glass and fine copper screen showing similar results.

At the indicated flow rates, the patterns and focal lengths are constant and steady when the mixed gases emerging from the tube are kept out of the light beam. This shows that the gas mixture is quite stable when laminar flow exists in the tube. The tube continued beyond the porous region exposed to the second gas for about $1\frac{1}{2}$ inches, but greater focusing power than that shown here was obtained with longer exit tube lengths. This indicates that the gases were still in laminar flow and were not completely mixed in this short length, so that focusing continued with

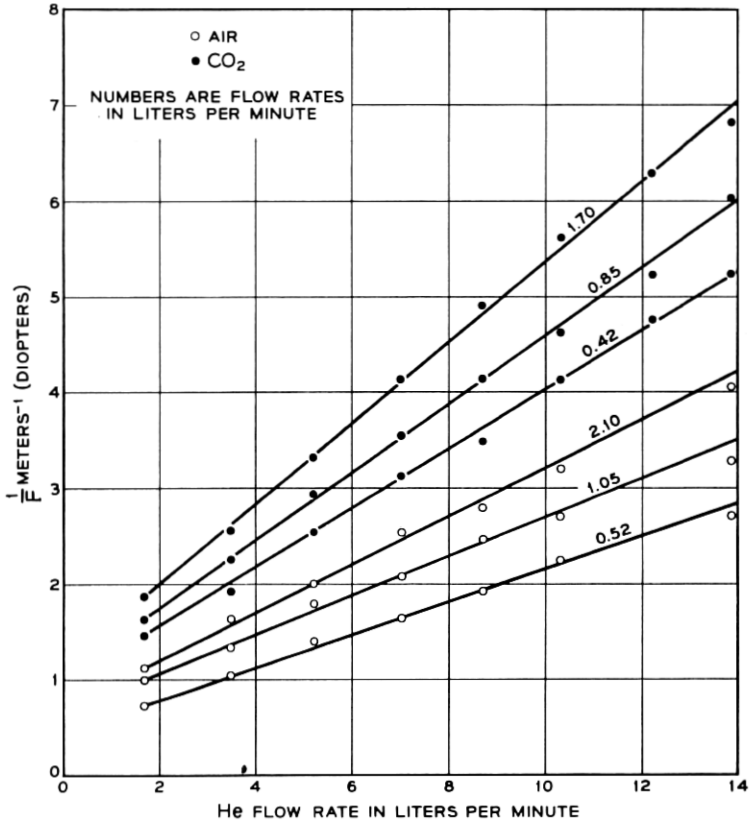

Fig. 2 — Lens focusing power versus gas flow rates, air-helium and carbon dioxide-helium.

more length. At higher flow rates, particularly of the gas first introduced into the system, turbulence appeared. This broke up the light beam and gave unsteady and flickering patterns on the screen.

Some photographs of patterns observed with gas mixture arrangements are reproduced on Fig. 4. At the upper left, the image of the beam is shown with no gases flowing in the tube. The diameter of this spot on a screen at any distance was about $\frac{1}{8}$ inch. At the upper right is the enlarged spot formed by carbon dioxide flowing down the tube and helium introduced through the porous tube walls at rather high flow rates so that a short focal length (approximately 6 inches) was obtained. This pattern, of course, increased in size as the screen was moved farther away. At lower flow rates, giving longer focal lengths, the light pattern is quite uniform, but as the focal length is made short, concentric rings

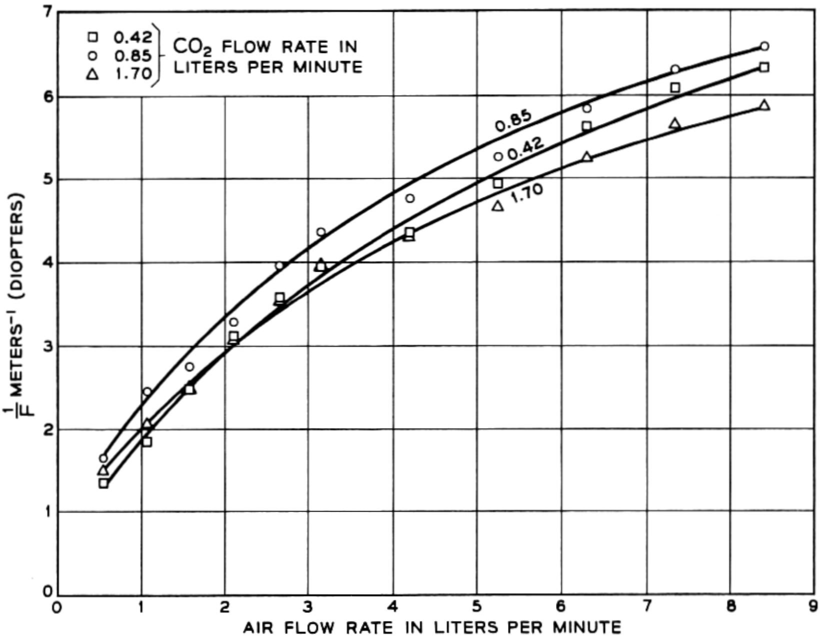

Fig. 3 — Lens focusing power versus gas flow rates, carbon dioxide-air.

of light begin to appear, as can just be seen here. These rings are similar to those which appear when spherical aberration forms a light interference pattern.[4] With a 3-inch porous tube, this effect is slight until very short focal lengths are produced. However, when the porous tube was replaced by two solid brass tubes in line with a gap of about $\frac{1}{10}$ inch between them at the center of the second gas reservoir, the light pattern shown in the photograph at the lower left was obtained. When the porous tube was replaced by a solid brass tube having six $\frac{1}{10}$-inch diameter holes drilled symmetrically every 60 degrees around its circumference in a plane located at the center of the second gas reservoir, the pattern at the lower right was observed. The use of tubes with different numbers of equally spaced holes produced patterns similar to this, having an n-fold symmetry where n is the number of holes. The steadiness and stability of these patterns of light interference are graphic indications of the stability of the gas flow, and the stability of gas lenses.

There are ways of separating the mixed gases, if desired, by permeable membranes or other means so that they can be mixed again in a later lens farther along a transmission system. Complete separation is not necessary to give lens action.

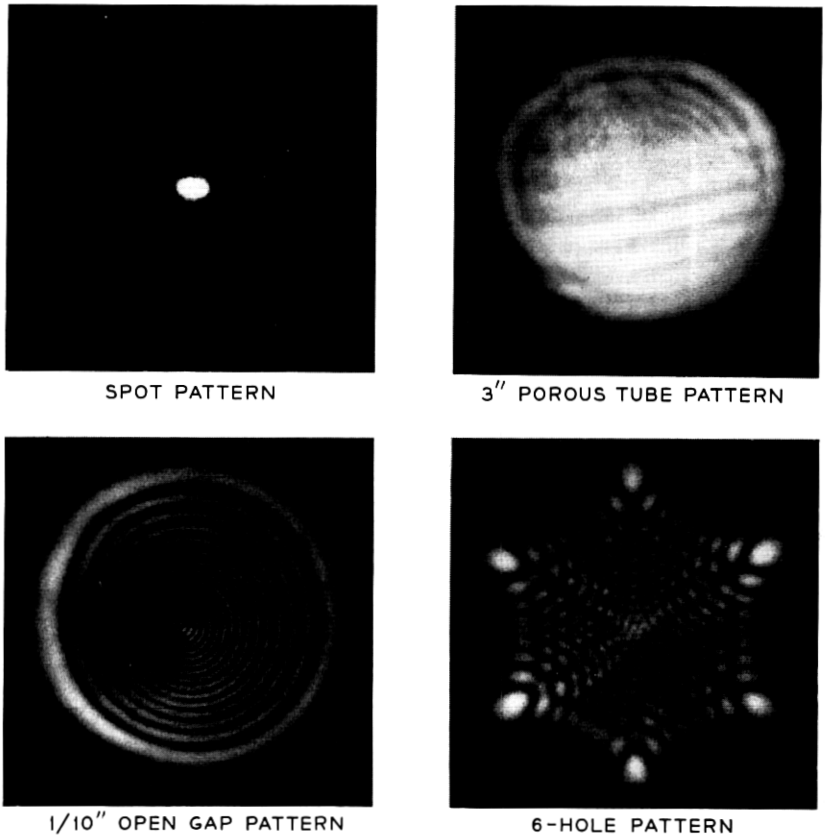

Fig. 4 — Observed patterns.

Gas mixture lenses can have short focal lengths with moderate gas flows. The effects are remarkably steady and constant. The focal length is easily changed by changing the gas flow rates. Such lenses may have possible uses in optical transmission systems.

The assistance of W. E. Whitacre in constructing and setting up the equipment is gratefully acknowledged.

REFERENCES

1. Berreman, D. W., A Lens or Light Guide Using Convectively Distorted Thermal Gradients in Gases, B.S.T.J., **43,** July, 1964, Part 1, p. 1469.
2. Berreman, D. W., A Gas Lens Using Unlike, Counter-Flowing Gases, B.S.T.J., **43,** July, 1964, Part 1, p. 1476.
3. Marcuse, D., and Miller, S. E., Analysis of a Tubular Gas Lens, B.S.T.J., this issue, p. 1759.
4. Born, Max, and Wolf, Emil, *Principles of Optics*, Pergamon Press, 1959, pp. 472–477.