Thermal Gas Lens Measurements

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The refractive index of a gas is an inverse function of its temperature under isobaric conditions. Therefore a cool gas flowing into a heated tube will have a lower refractive index near the heated walls than in the center, and the combination becomes a convex lens which will focus a light beam transmitted through the tube.[1,2]

A simple arrangement was built to get some information about the behavior of such a device. It is sketched in Fig. 1. The gas flowed through a 5-inch long electrically heated brass tube with a $\frac{1}{4}$-inch inside diameter. The tube was mounted in a large polyfoam cylinder to reduce external heat losses. 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 heated tube, through which a gas was flowing. The light was intercepted on a screen about 10 to 20 feet away. When this system, acting like a convex lens, is placed in such a collimated beam, the light goes through a focus at the lens focal length, and then expands to form a much larger area of light on the screen. A Foucault knife edge cutting the beam at the focus was used for measuring the focal length of the lens.

The reciprocal of the lens focal length in meters (often called the focusing power or convergence of the lens, and usually expressed in diopters) is plotted as a function of wall temperature rise on Fig. 2. Measurements were made with air and with carbon dioxide at the indicated flow rates. Helium was found to give very small effects, as expected.[2]

It will be noted from Fig. 2 that the lens power increases more slowly with flow rates at the higher values. At somewhat higher flow rates it flattens off and stops increasing, but at these very high flow rates, gas turbulence sets in and laminar flow is no longer present, so accurate measurements become impossible. At the flow rates shown on Fig. 2, constant and steady light patterns and focal lengths are observed when heated gas emerging from the tube is kept out of the light beam. This indicates that when laminar flow exists, the gas is very stable in a tube as small as this one; therefore steady optical lens effects are obtained. At higher temperatures the lens power continues to increase, at least up to the temperatures obtainable with this equipment. At the highest lens powers there is an effect that appears like spherical aberration,

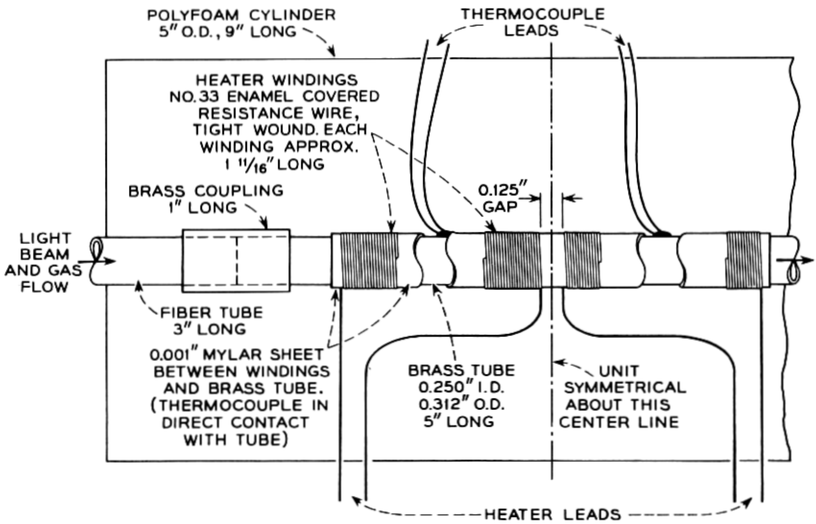

Fig. 1 — Experimental arrangement for thermal gas lens.

shown by a concentric pattern of light rings beginning to appear on the screen,[3,4] but this is very slight in the ranges shown on Fig. 2.

The brass tube was heated with direct current, and the input electrical power was measured for all points. The electrical power required with no gas flow was also measured as a function of temperature. The heat power taken away by the flowing gas was the difference between these two values at the measured temperature rise. From this information, a "figure of merit," defined as the reciprocal of the focal length in meters divided by the watts of heat extracted by the flowing gas (diopters per watt), can be calculated.

Representative data, and some comparisons with theoretical values, are summarized in Table I. The theory, notation, and gas constants are given by Marcuse and Miller.[2]

Agreement between calculated and measured values is fair for heat power consumption of the flowing gas, but not as good for focusing power, particularly at large flow rates of the heavy gas.

The focusing power and figure of merit of these lenses can be improved by using longer sections of tubing, since this one was not optimized. They may also be improved by using other gases having a higher $(n - 1)/k$ ratio, where n is the refractive index and k is the heat conductivity of the gas, and by operating at higher gas pressures.

Thermal gas lenses have short focal lengths with low power consumptions, and the effects are remarkably steady. The focusing power can

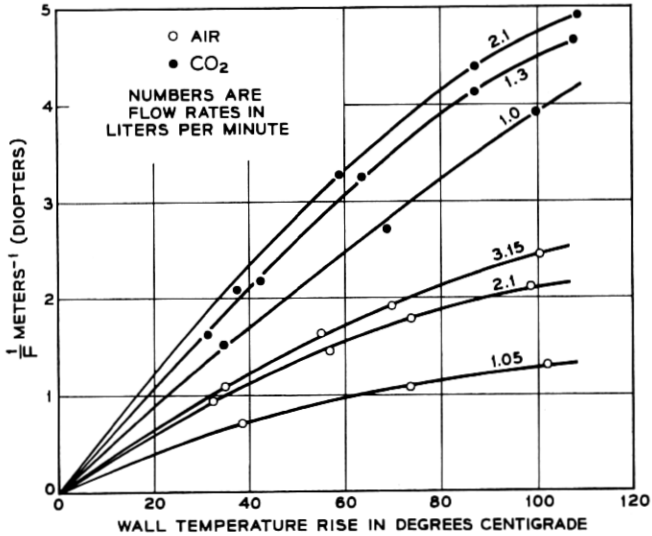

Fig. 2 — Lens focusing power versus wall temperature rise.

be adjusted easily by changing the gas flow rate. Such devices may find applications to long distance optical communication systems.

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TABLE I — REPRESENTATIVE DATA AND THEORETICAL VALUES

Gas	Flow Rate (liters/min)	V (cm/sec)	v_0 (cm/sec)	v_0/V	1/F (diopters)		Power (watts)		Figure of merit (diopters/watt)	
					calc.	meas.	calc.	meas.	calc.	meas.
Air	1	27.24	105	3.87	1.67	1.3	1.74	1.8	0.96	0.72
Air	2	27.24	211	7.74	1.95	2.1	2.75	2.9	0.71	0.72
CO_2	1	13.52	105	7.80	3.00	3.8	1.73	2.0	1.73	1.90
CO_2	2	13.52	211	15.6	2.02	4.7	2.49	2.9	0.81	1.62

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