

XVII. NEUROPHYSIOLOGY*

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A. NOVEL OPTICAL SYSTEM FOR COUNTING DROPLETS IN SUSPENSION

In the course of our experiments with reflexive optical systems, we have developed a method for illuminating transparent droplets in suspension (or bubbles in solution) which may have application to drop-size measurement (disdrometry), or to fluid-flow visualization. More specifically, this new method permits us to define a plane of illumination in a three-dimensional space with greater accuracy than is permitted by conventional slit-illumination methods. Droplets crossing this plane of illumination will emit a pulse of light indicative of the size of the drop. The resultant improvement in spacial resolution should permit higher counting rates and/or discrimination of finer droplets than heretofore.

The principles of operation are explained with reference to Fig. XVII-1. Light from source Y passes through polarizer P_1 and is reflected downward by a beam-splitting prism B. (The undeflected beam is absorbed by black baffles Z and Z'.) A fraction of the downwardly directed polarized beam is intercepted by droplets D_1 , D_2 , D_3 , etc. Rays passing through these drops will converge at foci F_1 , F_2 , F_3 , below the droplets, and will subsequently diverge; the divergent rays will be collected by a wide-aperture lens objective, L. This lens is oriented to have its principal focal plane at XX' , and conjugate focus at infinity.

Rays that pass through the lens are returned in the same direction by a triple mirror or corner reflector, T, located immediately below the lens. A half-wave plate, H, semi-circular in shape so as to intercept each ray once, either before or after passing through the corner reflector, rotates the plane of polarization of the returning rays by 90° . Those rays which are undeflected by droplets are blocked by the absorbing and occluding disc, M, located at the conjugate image of the light source. The rays which were originally diverted by the droplets after passing twice through the lens will reassemble at the conjugate focal points, F'_1 , F'_2 , F'_3 , etc. For the purpose of this example, we shall assume that droplet D_3 is so positioned that its foci F_3 and F'_3 are coincident in plane XX' . The light rays which were originally scattered by this droplet will be reassembled so as to reform a beam returning in the direction of the light source (and the observer). Light

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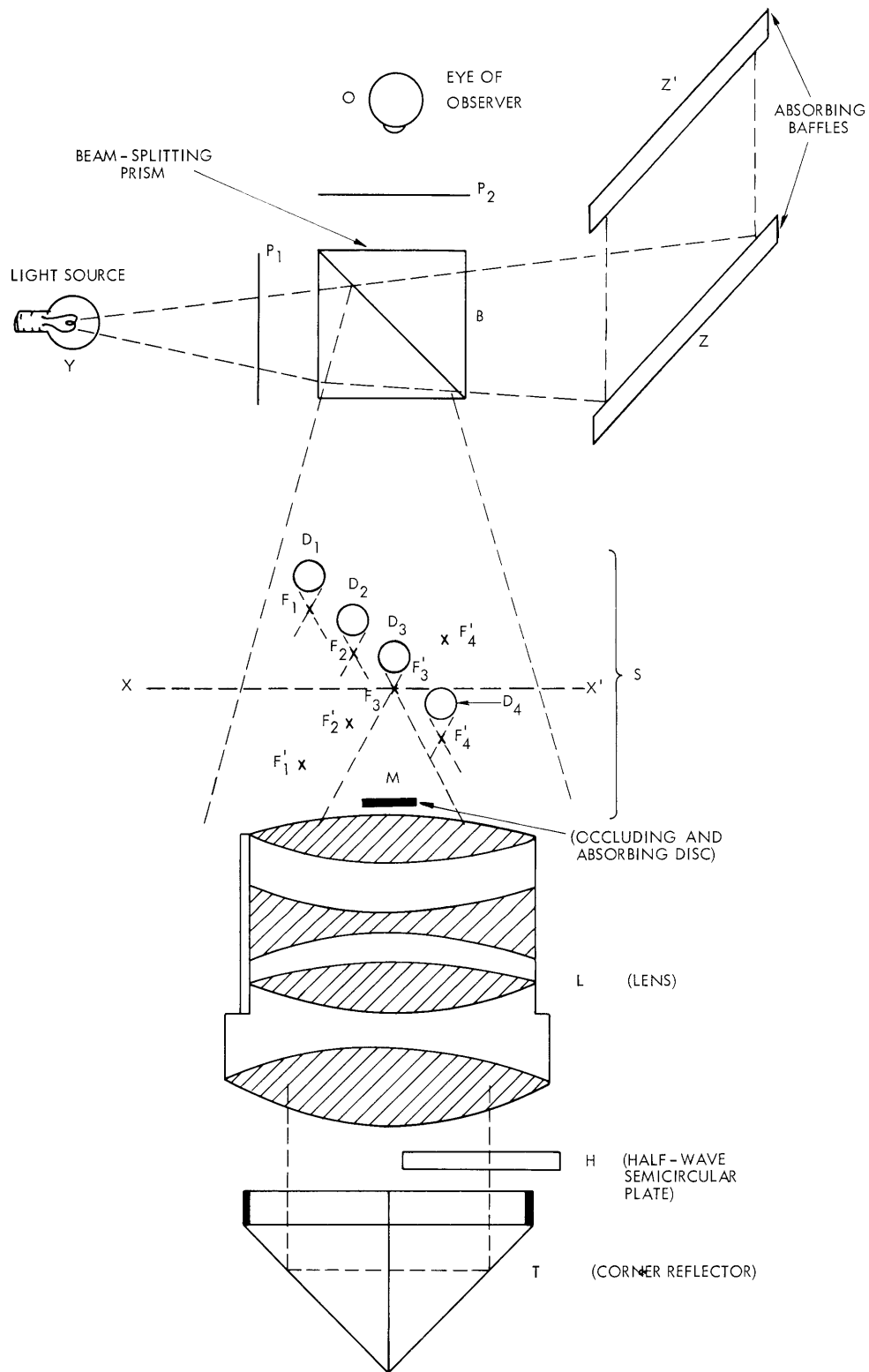


Fig. XVII-1. Optical system for droplet illumination.

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scattered by each of the other droplets will reassemble at points either too low or too high to be effectively collimated by these same droplets, and their images will be less apparent to the observer. The rotation of the plane of polarization of the reflected rays permits us to place a second cross polarizer P_2 in front of the observer with small added attenuation; this polarizer will block the direct specular reflection from all of the droplets in space S (regardless of position).

We see that the cooperative action of this arrangement of elements is such as to render visible only those droplets in the space S which are so positioned to have their foci located within narrow limits of the focal plane (or, more generally, surface) of the lens L. To the casual observer, the effect is that which one would associate with a narrow-slit illumination from the edge; one difference being that the droplets light in the center.

A closer examination of the properties of this optical system reveals the following additional points. (a) The peak response to a droplet of given size as measured by the total light reaching the observer (who might be replaced by a phototube) can be substantially independent of the coordinates of the droplet in plane XX'. (b) Suitable choice of the size of the occluding stop, M, allows us to eliminate the central portions of the cone of light returned toward each drop by the lens system; thus if the droplet be more than a few radii from the position of maximal illumination, it will be in complete eclipse, and hence invisible to the observer. (c) If a suspension of droplets is propelled at constant velocity in a normal or oblique direction past the plane of focus, each droplet will emit a pulse of light of duration and intensity characteristic of its size. (d) The limitation of the special resolution of this system along the axial direction is determined by the diffraction limit of a wide-aperture lens, and is necessarily an improvement over that which it is possible to attain with a comparable working volume with any possible system of slit illumination.

Detailed Design Considerations and Results with a Scale Model

The performance of the optical system described here is largely determined by the properties of the lens. A particular requirement of special importance is the need for wide aperture, so as to achieve, in effect, minimum depth of field. Wide aperture is usually incompatible with best resolution, which is also a desirable feature if we are to resolve fine droplets. In this special application, however, it is not necessary to control all the primary lens aberration to the degree customary. Table XVII-1, in which these seven major aberrations are listed, makes this point. With the relaxation of the need for correction of lateral chromatic aberration and distortion, it may be possible to effect considerable improvements in the resolution of wide-aperture lenses. If the light source is monochromatic, the freedom from three of the seven usual

Table XVII-1. Effect of lens aberrations on performance of planar illumination.

<u>Aberration</u>	<u>Remarks</u>
1. Spherical aberration	Must be controlled
2. Astigmatism	Must be controlled
3. Coma	Effect undetermined
4. Distortion	Unimportant
5. Curvature of field	Unimportant for particle-counting applications
6. Lateral chromatic aberration	Unimportant
7. Axial chromatic aberration	Important unless illumination is monochromatic

constraints would be very likely to permit improvements in resolution and aperture.

In order to provide experimental verification of this method of illumination a large-scale model was constructed. The droplets were simulated with glass beads of a sort used for chemical catalysis; they were made of borosilicate glass, and were roughly spherical.

Two different lens objectives were employed for these tests: (a) a 150-mm, f 1.8, Astro-Berlin, "Projektions-Tachar" lens, an extremely high speed four-element long focal length objective, intended for small and medium format (6 cm × 6 cm) photography. This lens has very good central resolution, and is well color corrected; its chief limitation for photographic purposes is a pronounced curvature of field. (b) a 7-inch f 2.5 Aero-Ektar (Eastman Kodak) aerial camera lens, intended for 5 in. × 5 in. format. This lens has also good resolution, is color-corrected and has a very flat field. These lenses were operated close to their full apertures, limited by the 6-cm diameter of the corner reflector. The polarizers were Polaroid, and the light source was a microscope illuminator. The occluding stop M was black velvet, and absorbing baffles Z and Z' were glossy black surfaces.

In Fig. XVII-2 we show the results of illuminating a collection of glass beads, roughly 2 mm in diameter, positioned so as to give maximal light return. (The beads were sandwiched between discs of optical glass; this and subsequent photographs were taken with a red filter to reduce the effect of secondary spectrum, or residual axial chromatic aberration.) In Fig. XVII-3 we show the results of inclining this same array of beads 30° to the plane of focus. Roughly, one row of balls is illuminated here, the others are dark, save for light scattered by inclusions and imperfections of the beads.

In Fig. XVII-4 we show the same display for beads of 1-mm diameter with a lesser

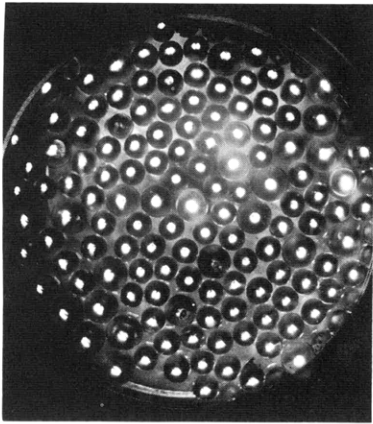


Fig. XVII-2.

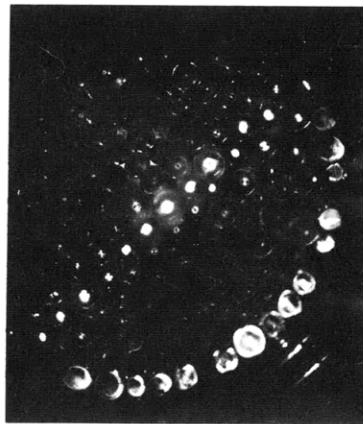


Fig. XVII-3.

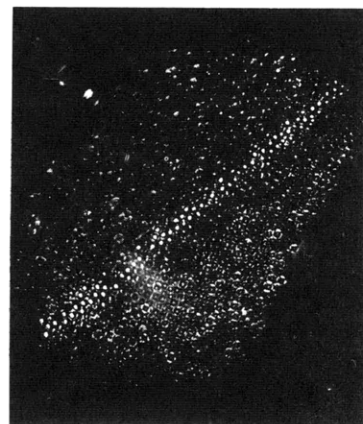


Fig. XVII-4.

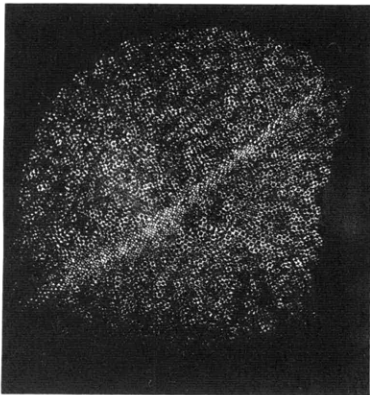


Fig. XVII-5.

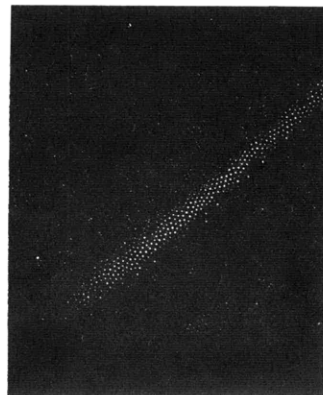


Fig. XVII-6.

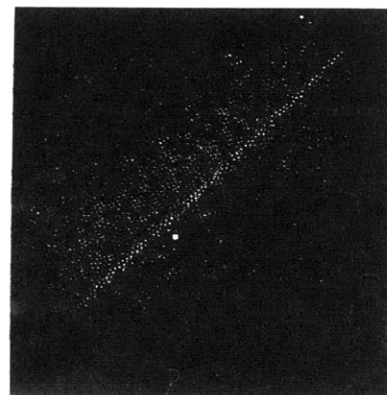


Fig. XVII-7.

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inclination; in Fig. XVII-5 the same picture for 0.5-mm beads. In the latter figure, the curvature of the illuminated track caused by the field curvature of the 150-mm lens is apparent. In Fig. XVII-6 we show the 0.5-mm beads slightly inclined ($\sim 15^\circ$) to the focal plane of the 7-inch Aero-Ektar lens; here, despite the reduced inclination of the beads, the locus of centers of illumination is very nearly straight.

In Fig. XVII-7 we show the result with the small (0.5-mm) beads, the Aero-Ektar lens, and an inclination of 40° ; in this picture, at most, two rows of balls, separated in depth 0.5 mm, are visible simultaneously. In these tests considerably depolarized light was returned by the balls, presumably because of inclusions. (There were no pronounced color fringes that are indicative of strains.) It is to be expected that

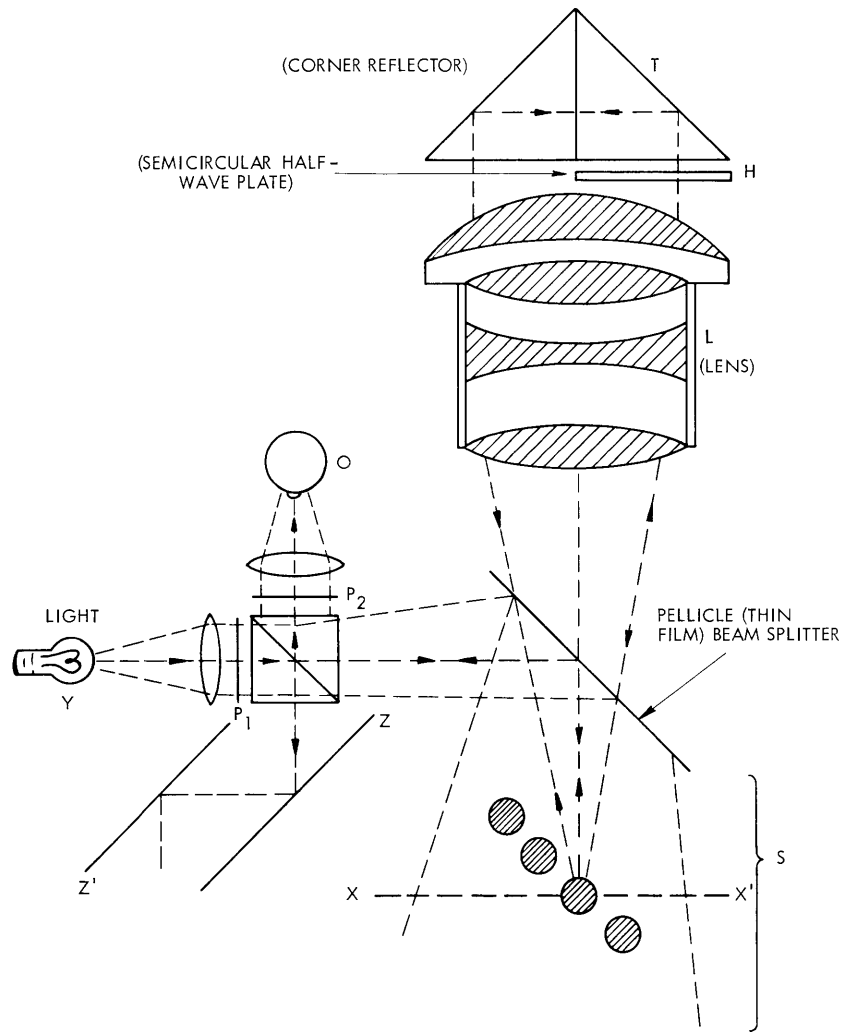


Fig. XVII-8. One-sided system for observing motions of a layer of bubbles.

operations with drops or bubbles would produce a display showing better contrast. The results presented here, however, should suffice to indicate the feasibility of the method.

We anticipate that this method of illumination may have applications in atmospheric studies, for example, as related to droplet or fog particle-size measurements. A model for such purposes could be constructed by using a microscope objective, with the triple mirror replaced by a spherical reflector at the conjugate focal surface. The availability of apachromatic wide-aperture objectives should prove advantageous. A second possible application of these methods might be to a problem in fluid-flow visualization. One technique now used for indicating the behavior of flowing fluid is the introduction, by electrochemical means, of a sheet of tiny hydrogen bubbles generated at a fine platinum-wire cathode. Since the paths of these bubbles will diverge in three dimensions, additional information would be gained if it were possible to illuminate selectively different layers of bubbles in depth. Since the geometry of particular flow situations may be unfavourable to transverse slit-illumination, and/or the resolution capabilities of slit-illumination may be inadequate, the use of the present scheme could prove fruitful. For these applications the "one-sided" system of Fig. XVII-8 may prove useful.

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