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ROTATING PRISM FOR USE WITH CLOUD CHAMBERS

Bernard G. Saunders

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Rotating Prism for Use With Cloud Chambers

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ABSTRACT

The use of a rotating prism is indicated when one wishes to observe moving cloud-chamber droplets and to measure their velocities. Equations are developed for computing displacements of droplets and their rates of displacement as a function of the prism's angular displacement and velocity. Also discussed are the limits of displacement and velocity of droplets that can be observed.

INTRODUCTION

One method of measuring the concentration of particles in a smoke is to allow the particles to serve as nucleation centers in a supersaturated vapor. Liquid droplets will condense on the particles, enlarging their apparent diameters a thousand-fold or more. It is then possible to photograph them macroscopically and count the number of images in a unit area of the film, corresponding to the number of particles in a unit volume of the smoke.

In cloud chambers[1] designed for this purpose, the axis of the camera is usually placed at right angles to the axis of illumination so that the space occupied by the droplets will have a measurable configuration. At an angle of 90°, however, the intensity of light scattered from the droplets toward the camera is only a few percent of that scattered in the forward direction[2]. So that even with

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1. Henry L. Green, "On the Application of the Aitken Effect to the Study of Aerosols," Phil. Mag. 4, 1046 (1927).

2. C. G. Webb, "On the Scattering of Light by Water Drops," Phil. Mag. 19, 927 (1935). Richard L. Lander and Carl E. Nielsen, "Scattering of Light from Small Drops," Rev. Sci. Inst. 24, 20 (1953).

carbon-arc illumination, an exposure the order of one-twenty-fifth second is required to capture the droplets. Unfortunately, during this period the droplets are in motion due to turbulence, Stokes' settling, etc., and elongated images appear on the film.

Green[1] obtained undistorted images of the droplets by retarding their motion with a counter-current of air. Wilson and Wilson[3] avoided Stokes' settling by dropping their camera and cloud chamber simultaneously and making the exposure in transit. The present paper describes how moving droplets can be made to appear stationary with the aid of a rotating prism.

THE PRISM

A. Displacement

The rotating prism[4] is a familiar optical device in motion-picture technology and is used in film editors, high-speed cameras and other instruments where film transport is non-intermittant. In Fig. 1, a droplet displaced a distance D from the optical axis will be imaged on the optical axis by a prism of thickness T and index of refraction μ when the prism makes an angle i with the axis. By geometrical optics, the relationship between D and i is

$$D = \frac{\sin (i - r)}{\cos r} T \quad . \tag{1}$$

Using Snell's law, $\sin i = \mu \sin r$, the equation can be expanded as follows:

$$D = \sin i \left[i - \frac{\cos i}{\mu} \left(1 - \frac{1}{\mu^2} \sin^2 i\right)^{-1/2} \right] T$$

$$D = \left(i - \frac{i^3}{6}\right) \left[1 - \frac{1}{\mu} \left(1 - \frac{i^2}{2}\right) \left(1 + \frac{1}{2\mu^2} i^2\right) \right] T$$

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3. C.T.R. Wilson and J. G. Wilson, "Falling Cloud Chamber and Radially Expanding Cloud Chamber," Proc. Roy. Soc. 148, 523 (1935).

4. Gerhard Schwesinger, "Reducing Aberrations in Rotating - Prism Compensators for Nonintermittant Motion Pictures," J.O.S.A. 42, 923 (1952).

$$D = (1 - \frac{1}{\mu}) \left[i + (\frac{\mu + 1}{2\mu^2} - \frac{1}{6}) i^3 \right] T , \qquad (2)$$

where all terms of order higher than i^3 have been discarded.

B. Velocity

When the droplet is moving along a normal to the plane defined by the optical axis and axis of rotation of the prism, its rate of displacement $v = dD/dt$ along the normal is related to the angular velocity di/dt of the prism as follows:

$$v = dD/dt = (1 - \frac{1}{\mu}) \left[1 + 3 (\frac{\mu + 1}{2\mu^2} - \frac{1}{6}) i^2 \right] T \, di/dt . \qquad (3)$$

Fig. 2 is a plot of the ratio of the droplet velocity to the angular velocity vs. the angle of incidence. The curve is essentially linear between $-\pi/8$ and $+ \pi/8$. That is to say, the image of a constant-moving droplet will remain fixed if (a) the rotational speed of the prism is constant, and (b) if the normal to the face of the prism does not make an angle with the optical axis that is more obtuse than about 22.5°. Condition (b) is satisfied by an eight-sided prism.

LIMITATIONS

For a prism having an index of refraction $\mu = 1.50$, Eq. 2 shows that the droplet can move a distance $D = 0.28T$ when the prism rotates through an angle $\pi/4$ (i.e., $-\pi/8$ to $+ \pi/8$). A rotating prism of thickness T = 1", for instance, will permit one to view or photograph a droplet moving through a distance of 0.28 inches.

The velocity of the droplet, by Eq. 3, is

$$v = .33 (1 + 1.17 i^2) T \, di/dt .$$

For $i = 0$,

$$v = .33 T \, di/dt ;$$

and for $i = \pi/8$,

$$v = 0.39 T \, di/dt .$$

If the prism rotates at the rate of ω revolutions/sec.,

$$di/dt = 2\pi \omega ;$$

or,

$$v = 2.44 \omega T .$$

When the prism is rotating, 8ω occultations occur each second. Thus, if a prism is used in the photography of a moving object, the exposure time, $t = 1/8\omega$ seconds, will be a function of the object's velocity, or

$$t = \frac{1}{8\omega} = \frac{2.44\ T}{8\ v} ;$$

or,

$$t = 0.305 \frac{T}{v} .$$

Droplets moving 2.5 ft/sec and "stopped" by a one-inch prism will expose a film 1/100 second, a time within the latitude of photographic emulsions. Droplets moving much faster can still be seen by the human eye, the speed of detection being limited only by their brightness.

When a prism is used as a stroboscope to detect or measure the speed of objects spaced equal intervals apart, or of an object with an evenly-spaced pattern (such as graph paper, gear teeth, or a sine wave), then the exposure time is independent of the prism rotation and depends only on the time the pattern or series of objects is in the field of view.

EXPERIMENTAL RESULTS

Fig. 3 is a diagram of a set-up that was used in calibrating an eight-sided prism[5] and checking the validity of Eq. 3. A Lucite disc 8 inches in diameter was rotated 3 r.p.m. by a 1/25 h.p. Bodine motor. A sheet of circular percentage (polar coordinate) graph paper was cemented to the face of the disc. Several dots were placed on a circle of radius r = 3.5 in. to give a lineal speed of $2\pi r\dot{\theta}$ = 1.1 in./sec, where $\dot{\theta}$ is in rev/sec of the disc. The prism was rotated at the speed required to stop the image in the eyepiece, namely, 0.43 rev/sec. For one rev/sec,

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5. Vendor: A. Jaegers, Lynbrook, New York.

this corresponds to a lineal speed of 2.56 in./sec.

In use, the prism was rotated in front of the window of the cloud-chamber. Fig. 4 shows a plan of the optical system. The prism increases the optical path by the increment

$$\frac{\mu - 1}{\mu} \frac{1}{\cos r} T = \frac{\mu - 1}{\mu^2 - \sin^2 i} T \quad .$$

The conjugate focus is thereby decreased, necessitating either a new position of the film holder or the camera lens. (For some applications it may be preferable to place the rotating prism between the camera lens and the film. In this case the prism must turn in the opposite direction and turn M = magnification times faster since the image is moving M times faster in reverse.)

Water droplets were formed on NaCl nuclei from a LaMer-Sinclair generator[6]. The speed of rotation of the prism was varied until the droplets appeared stationary. Multiplying the speed in r.p.s. by the factor 2.56 gave the speed of the droplets in in./sec.

The water droplets shown in Fig. 5 were photographed through the octagonal prism at 2.4x magnification during a 1/25 sec interval. Fig. 5a is a photograph of the droplets taken through the prism while stationary. Fig. 5b is a photograph of the same aerosol when the prism was rotated at constant speed. Fig. 5c was taken with the prism rotating at half-speed.

CONCLUSION

A rotating prism of octagonal cross-section was used successfully in photographing moving droplets in a cloud chamber. It was found to be useful in (a) measuring the velocity of droplets and studying their acceleration, (b) measuring the relative lateral displacement of droplets in convection currents, and (c) determining the direction of motion of fast-moving droplets during an expansion period.

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6. C. K. LaMer and D. Sinclair, "Light Scattering as a Measure of Particle Size in Aerosols," Chem. Rev. 44, 245 (1949).

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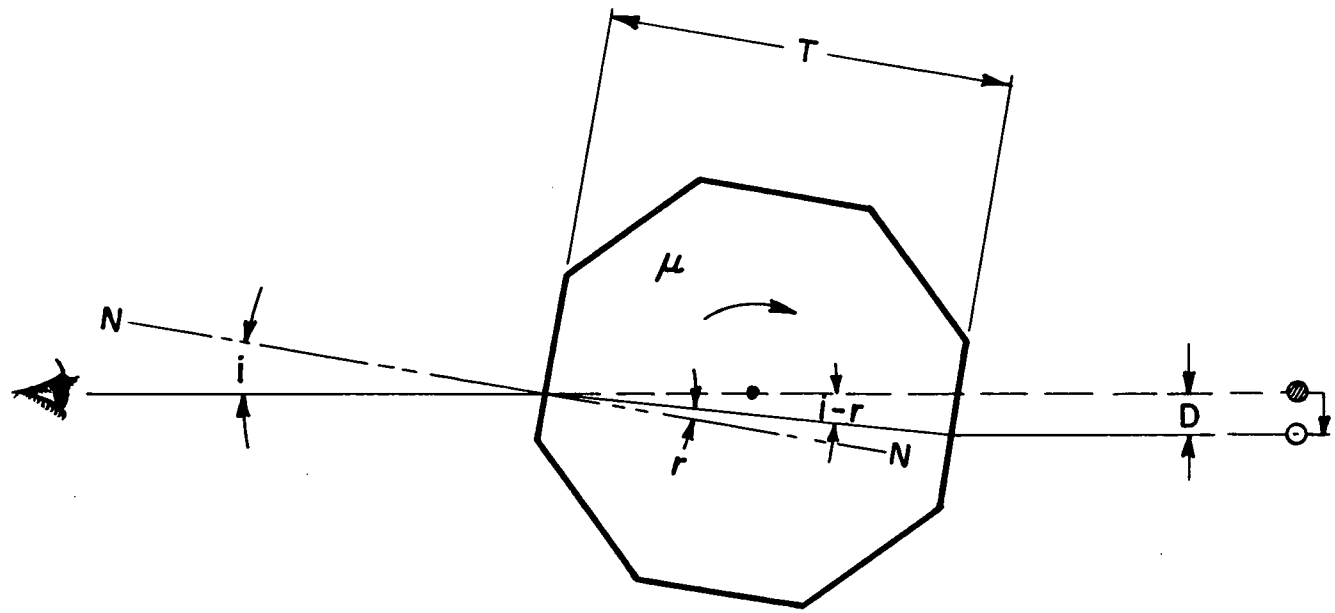

Fig. 1. Diagram showing how the prism of refractive index μ and thickness T must turn through angle i to compensate for displacement D of droplet. Droplet will appear to remain on optical axis.

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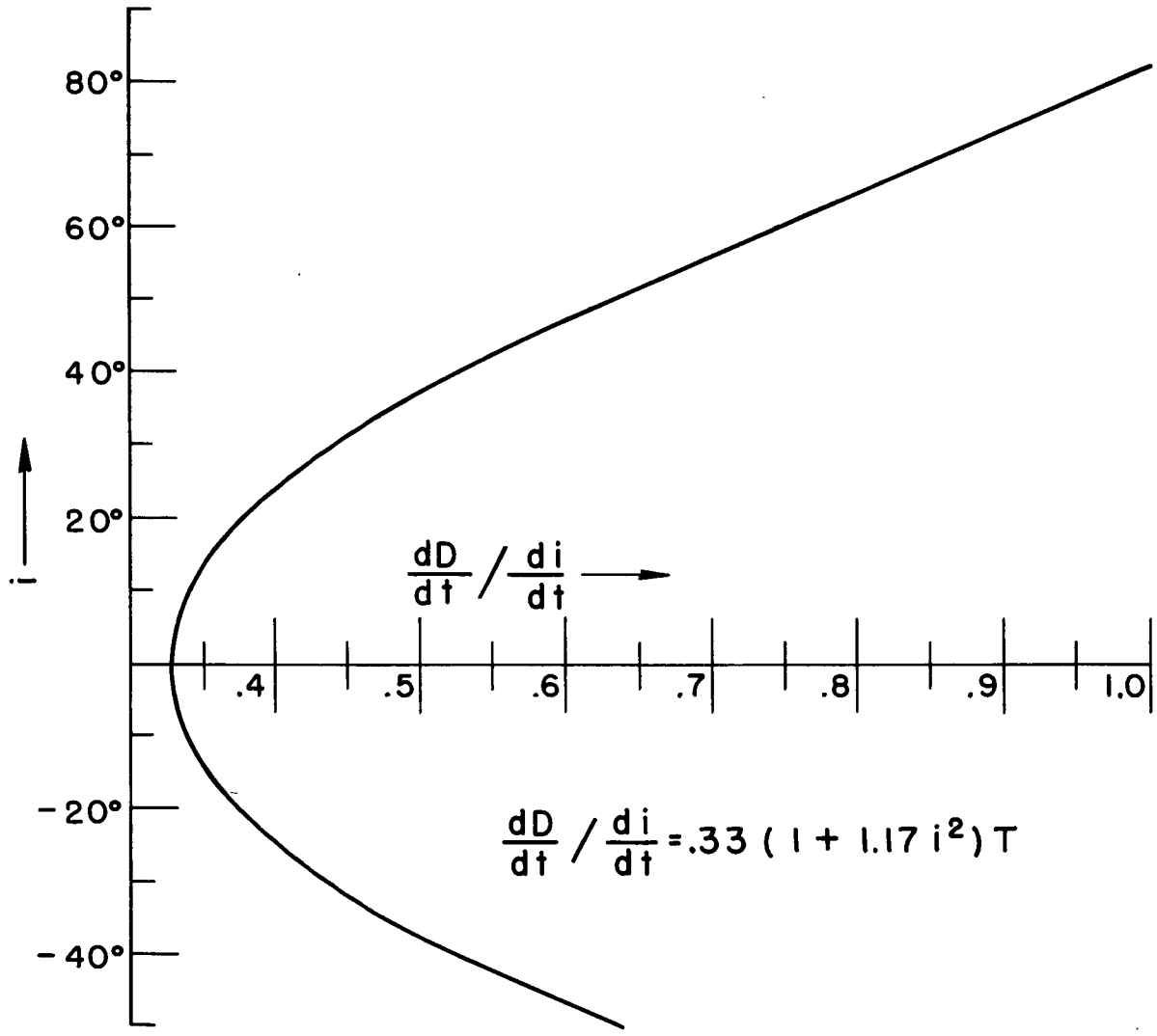

Fig. 2. Curve showing how ratio of droplet's velocity dD/dt to prism's angular velocity di/dt is affected by angle i that the normal to prism face makes with the optical axis.

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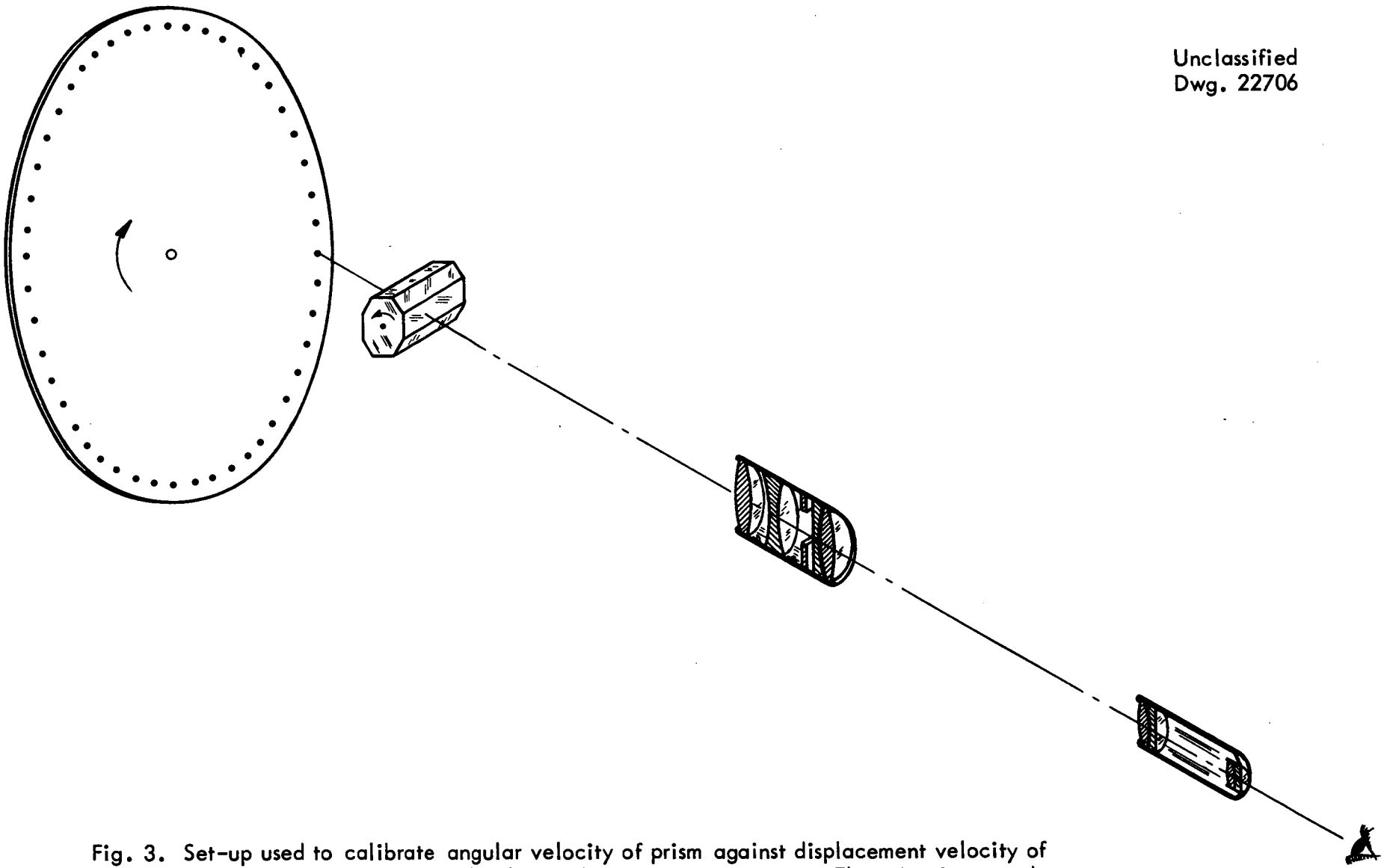

Fig. 3. Set-up used to calibrate angular velocity of prism against displacement velocity of droplets. Dots on rotating disc simulate droplets and move at constant rate. The prism is rotated at a speed at which the dots appear stationary when viewed through the eyepiece and camera objective.

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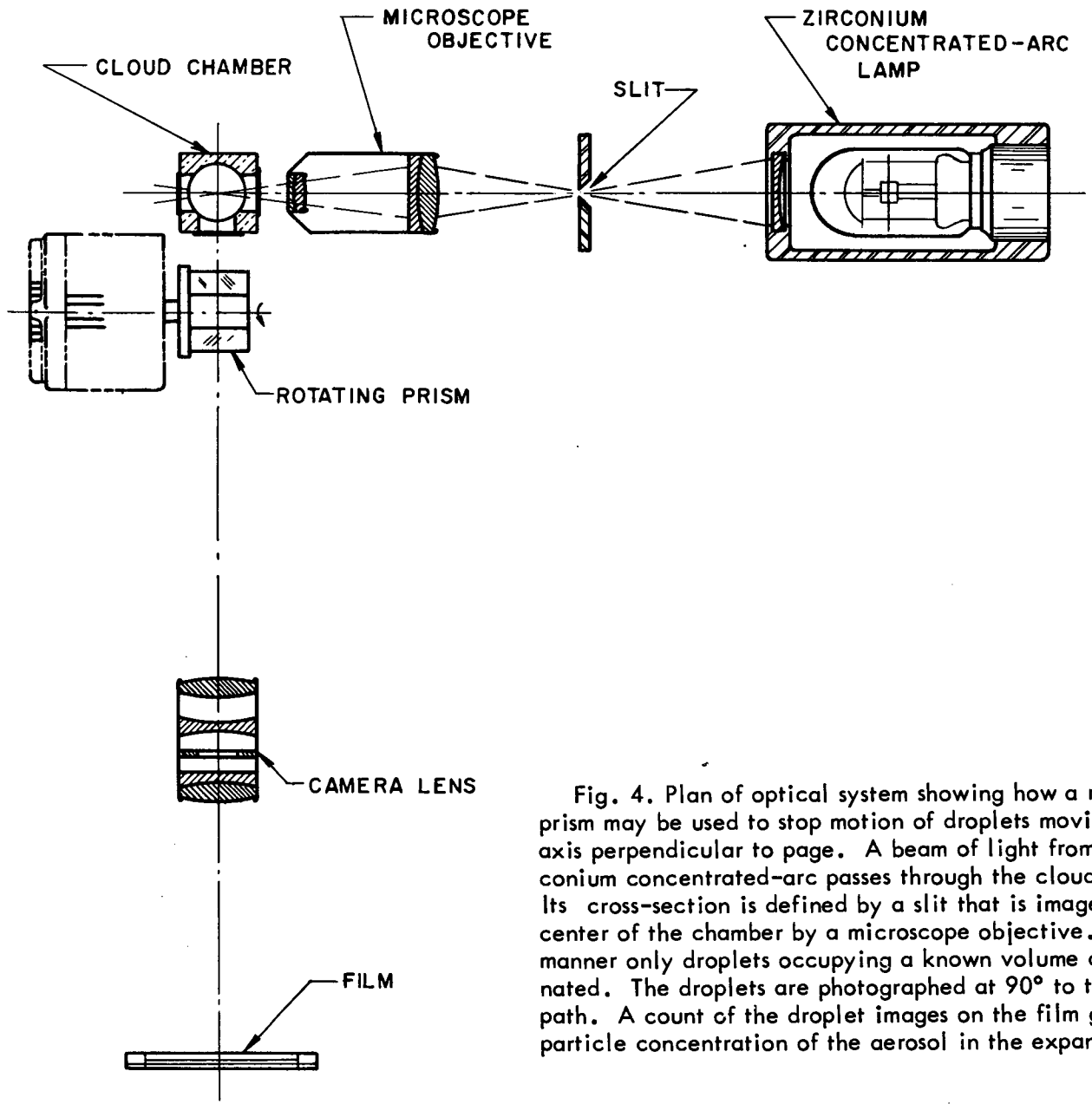
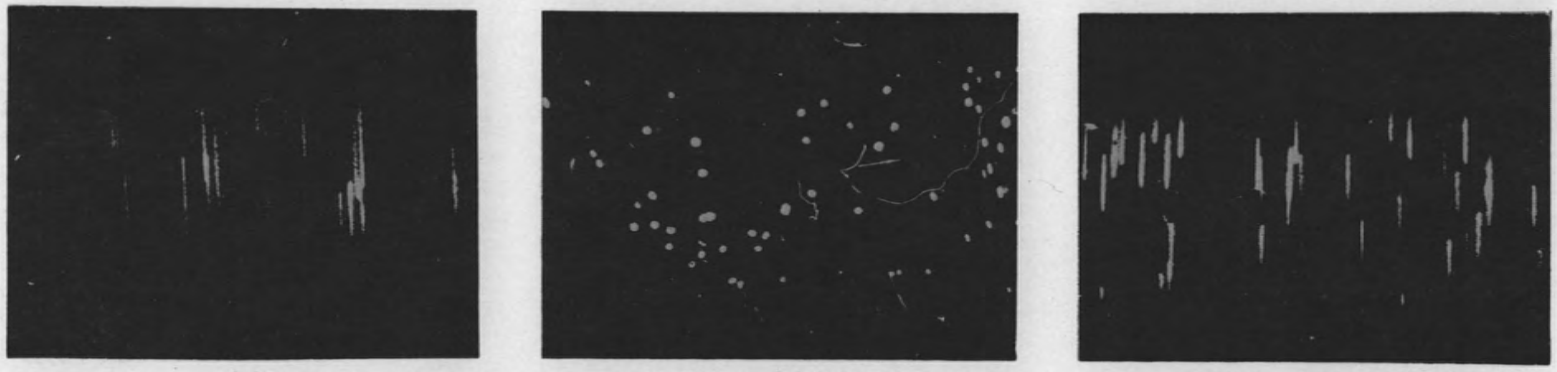


Fig. 4. Plan of optical system showing how a rotating prism may be used to stop motion of droplets moving along axis perpendicular to page. A beam of light from the zirconium concentrated-arc passes through the cloud chamber. Its cross-section is defined by a slit that is imaged at the center of the chamber by a microscope objective. In this manner only droplets occupying a known volume are illuminated. The droplets are photographed at 90° to the beam path. A count of the droplet images on the film gives the particle concentration of the aerosol in the expanded chamber.



(a) (b) (c)

Fig. 5. Water droplets in motion photographed through an 8-sided prism at 2.4x magnification: (a) stationary prism, (b) rotating prism, (c) prism rotating at half-speed.