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A GENERAL PURPOSE WIDEBAND OPTICAL SPATIAL FREQUENCY SPECTRUM ANALYZER

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A GENERAL PURPOSE WIDEBAND OPTICAL SPATIAL FREQUENCY SPECTRUM ANALYZER

by

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I. INTRODUCTION

There are a number of applications for which it is necessary to study the light scattered at various angles by a transparent media. One example of these applications would be the measurement of the optical Fourier spectrum resulting from various spatial frequencies which have been recorded on a photographic emulsion. One method for obtaining these measurements[1] consists of illuminating the test object with parallel monochromatic light. A stationary lens, placed in the resulting wavefield at a distance of one focal length from the object, will focus parallel waves emanating from the test object at a point lying in the focal plane of the lens. A light detector with a small filtering aperture is then used to measure the intensity variation of the light in the focal or transform plane of the lens. Such measurements require the use of a lens which is highly corrected for all of the common aberrations except chromatic aberration. Also, the lens must be characterized by a large numerical aperture if the intensity of light scattered at even moderately large angles is to be measured. In order to obtain the complete scattering spectrum of a test object it would be necessary to observe all angles from zero to 90 degrees, which would not be possible with such a fixed lens system.

To overcome the disadvantages of a fixed lens system, an instrument has been constructed and is in use in this laboratory with which it is possible to obtain the entire scattering spectrum of a transparent medium over a range of ±90 degrees, using only a simple lens corrected for minimum spherical aberration. The main feature of the instrument is that the lens, the small filtering aperture, and the detector are mounted as a unit upon an arm that rotates in an arc about the sample. The prototype of this instrument has been described in the NGL 04-001-007 reports of September 30, 1969 and April 1, 1970. Since that time the instrument has been rebuilt and extensively modified in a manner such that its sensitivity and usefulness are increased. The modified instrument in its present configuration is the subject of this report.

II. GENERAL DESCRIPTION OF THE INSTRUMENT

A diagram of the instrument is shown in Figure 1. The light from a Helium-Neon laser is expanded, collimated, and directed so as to be incident upon the sample. That portion of the light scattered at an angle "A" is focused by the lens onto a pinhole spatial filter. The light passing through the filter is incident upon a detector, whose output is ultimately displayed on a recorder. Light reaching the lens at angles other than "A" is removed by the spatial filter. The focusing lens, the pinhole, and the detector are mounted together upon an arm which rotates about the point shown. This arm is motor driven, allowing light scattered at all horizontal angles between ±90 degrees to be detected. With such an arrangement the focusing lens needs to be corrected only for spherical aberration, since the problems arising from coma, from curvature of field, and from other off-axis effects are eliminated.

The light source currently in use on the instrument is a 1 mW Helium-Neon CW laser operating at a wavelength of 6328 A. The output of this laser beam is approximately 2 mm in diameter. The beam is expanded by means of a collimator which consists of a 20X microscope objective, a 5 micron pinhole aperture which effectively filters out any deviated rays caused by various optical imperfections, and a long focal length collimating lens. The long focal length lens permits the beam to expand over a relatively long distance before collimation. In this way, only a small portion of the expanding beam will be collimated and localized intensity variations are minimized.

Due to the extremely low signals to be measured, it has proved necessary to eliminate all stray light from the instrument proper. For this reason, the instrument is located in a dark room which is separated from the laser source and all operating controls. The laser light, after being collimated is passed through an aperture in the wall. The aperture can be closed by the operator by activating a standard camera shutter. The beam also passes through a small diameter tube which acts as a light trap, effectively blocking all external light from the room when the aperture shutter is open. The incoming laser radiation is then incident upon the sample.

For analysis, the sample is placed in an adjustable holder. Adjustments along three orthogonal axes allow for exact positioning of the sample. The holder also allows the sample to be rotated 360 degrees about the axis of the laser beam, if desired.

An inexpensive simple lens, corrected for minimum spherical aberration, is used to focus the radiation scattered by the sample at any particular angle. Since the arrangement of the instrument is such that all rays to be measured at a given time are always parallel to the axis of the lens, no further corrections are necessary. A pinhole spatial filter placed at the focal point of this lens allows only the radiation leaving the sample at one particular angle to be detected. Actually, rays of a small angular range are passed by the pinhole due to its finite width. The use of large diameter pinholes increases the quantity of light which is observed, but this is accompanied by a loss in angular resolution. Provision has been made to interchange pinholes of various diameters so that measurements can be made which insure the maximum angular resolution consistent with the quantity of scattered light available for measurement.

An EMI 9558B photomultiplier tube is used as the primary energy transducer in the optical system. This tube has a 2 inch diameter, flat-faced, Pyrex end window with 11 venetian blind dynodes having CsSb secondary emitting surfaces. The photocathode is of the S-20 or tri-alkali (NaKSbCs) type having a quantum efficiency of 6 percent near 6328 A. The typical gain of the dynode section is near 2×10^6. Because of the low level signal current involved, a mu-metal shield is wrapped around the tube to reduce any electromagnetic interference. This shield is held at photocathode potential. If this is not done, field interactions with electrons leaving the photocathode occur and electron collection efficiency decreases.

If necessary, the incident light level on the photocathode can be limited by inserting neutral density filters in front of the entrance aperture of the photomultiplier tube. An attenuator box has been mounted in front of the tube in which 4 glass or gelatin filters measuring 2 inches by 2 inches can be easily inserted. An aluminum cover plate seals off any light which might enter the photomultiplier through the attenuator box. A camera shutter is mounted behind the attenuator box so that the photomultiplier can be optically isolated from all external light sources if desired.

The focusing lens, pinhole spatial filter, and detector assembly are mounted upon an arm whose axis of rotation passes vertically through the sample. This arm can be rotated through an angle of ± 90 degrees with respect to the incident laser illumination. In order to scan the scattering spectrum of a sample, the arm is motor-driven through the desired angular range. The motor mount has been constructed so that reversable synchronous motors of different speeds can be quickly interchanged to provide various scan rates.

The physical arrangement of the instrument is shown in Figure 2. Figure 2 is a double exposure which illustrates the manner in which a spectrum is scanned. The focusing lens, pinhole, and detector assembly is shown at angles of approximately 10 degrees and 85 degrees from the normal. The laser light source and all controls necessary for the remote operation of the instrument are located in an adjacent room directly behind the wall to the right in Figure 2. These controls include the photomultiplier high voltage supply, current to voltage converter, potentiometric recorder, and scan drive motor controls.

III. EXPERIMENTAL RESULTS

The performance of the instrument has been checked by measuring the diffraction patterns of several samples whose patterns are well known and can easily be verified mathematically. The samples consisted of single slits of several widths and a number of Ronchi rulings. In all cases the pattern as measured by the instrument was that which was expected.

Figure 3 shows the spectrum obtained when a 150 lines per inch Ronchi ruling was used as a test object. The recording begins with the zero-order beam at the left and continues through approximately 45 degrees. The vertical axis of the figures represents the relative intensity of the light detected by the photomultiplier as the sample spectrum was being scanned. These intensities covered seven orders of magnitude. Multiplication factors applying to the appropriate portions of the recording are indicated above the horizontal axis. For all multiplication factors of 10^{-5} and higher the photomultiplier dark current was 1 percent of the full scale reading. At 10^{-7} the dark current was 10 percent of the full scale signal. These values are indicated on the recording. It is pointed out that the instrument was not being operated at maximum sensitivity when this recording was made. The removal of all of the neutral density filters from the front of the photomultiplier would have permitted the highest diffraction orders to have been recorded with a dark current of 0.1 percent of the full scale signal. Other instrumental background signals are negligible over the entire spectrum. This spectrum was also scanned at a rather rapid rate so that the recording would be linearly compressed and more easily reporduced.

Figure 4 illustrates the type of data obtainable from the spectrum analyzer. It was desired to measure the intensity of light scattered at large angles by a high resolution photographic emulsion that had been developed but not exposed. This condition would correspond to the gross fog level of the emulsion. The solid curve is the background signal obtained when there is no sample present in the sample holder. This background consists mainly of the photomultiplier dark current. The dashed curve is the scattering spectrum obtained from a Kodak 649-F emulsion which has been developed but not exposed. In order to determine what portion of this scattering was caused by the glass substrate upon which the emulsion is supported, the emulsion was removed from the substrate and the scattering spectrum of the glass plate alone was obtained. This spectrum is shown by the dotted curve of Figure 4. At approximately

7 degrees there is a large increase in the background signal. This is caused by the edge of the focusing lens passing into the intense non-scattered or zero order beam. If it is desired to observe the sample spectrum within the range where the scattering from the lens aperture is a problem, a number of methods are available which allow this effect to be moved to other, non-critical regions. The simplest method is to alter the diameter of both the incident beam and the focusing lens aperture. At the present time scattering at angles larger than 7 degrees is of primary interest and the instrument has been set up with this in mind.

In conjunction with other experimental work being performed in this laboratory, it was desired to obtain the scattering spectrum for a polydisperse submicron size dioctyl-phthalate aerosol. The resulting spectrum of the aerosol is shown in Figure 5, which demonstrates the use of the instrument for measurements with suitable dynamic systems.

The instrument in its present form is suitable for many applications in which it is necessary to measure with great sensitivity and precision the intensity of light emanating at large angles from a sample. Such applications include the scattering spectrum of various transparent media, grating diffraction efficiency measurements, optical Fourier analysis, the measurement of hologram signal/noise ratios, and certain appropriate dynamic systems measurements.

IV. REFERENCES

1. Goodman, J. W., "Introduction to Fourier Optics", McGraw Hill Book Co., New York, 1968.

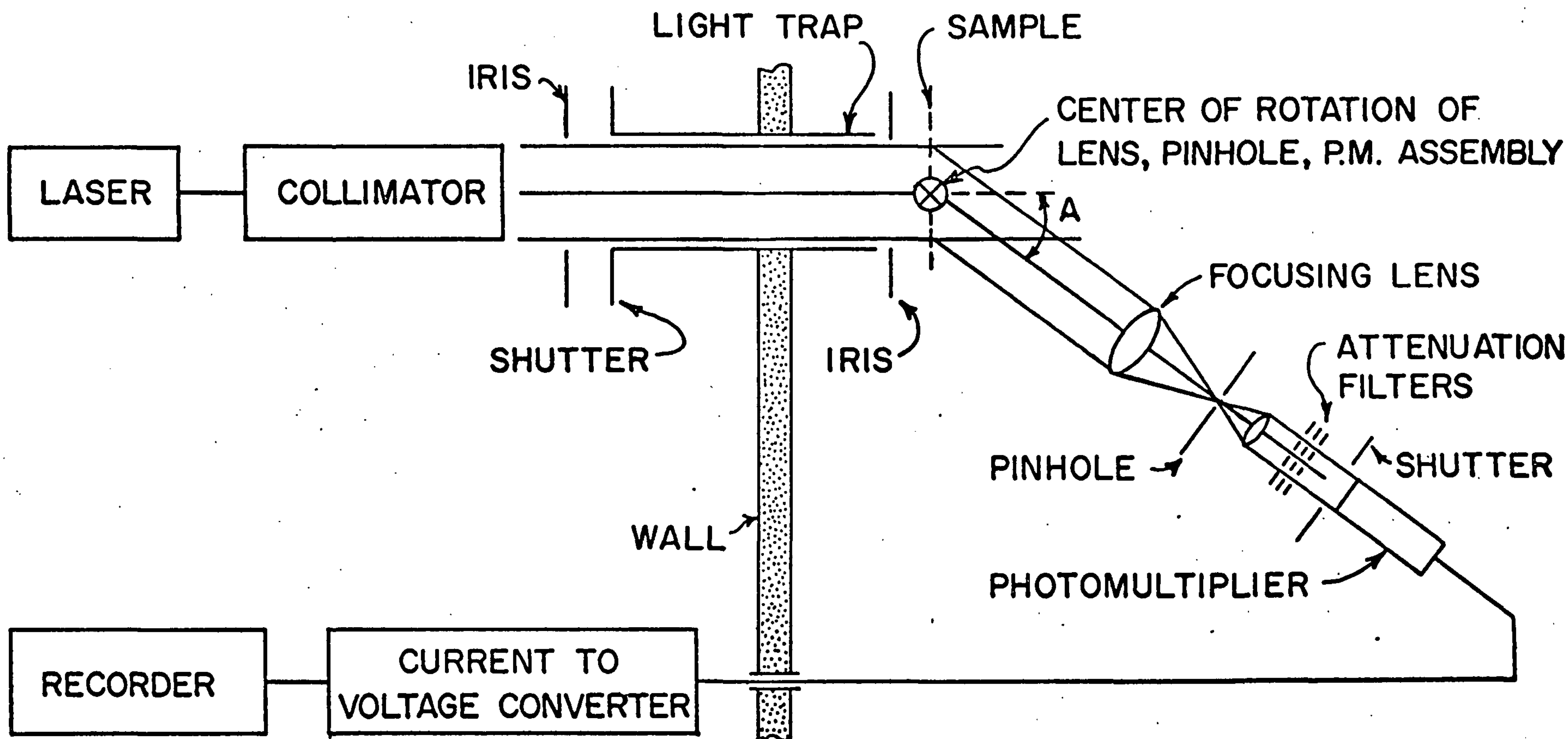

FIGURE 1

Wideband Spatial Frequency Spectrum Analyzer

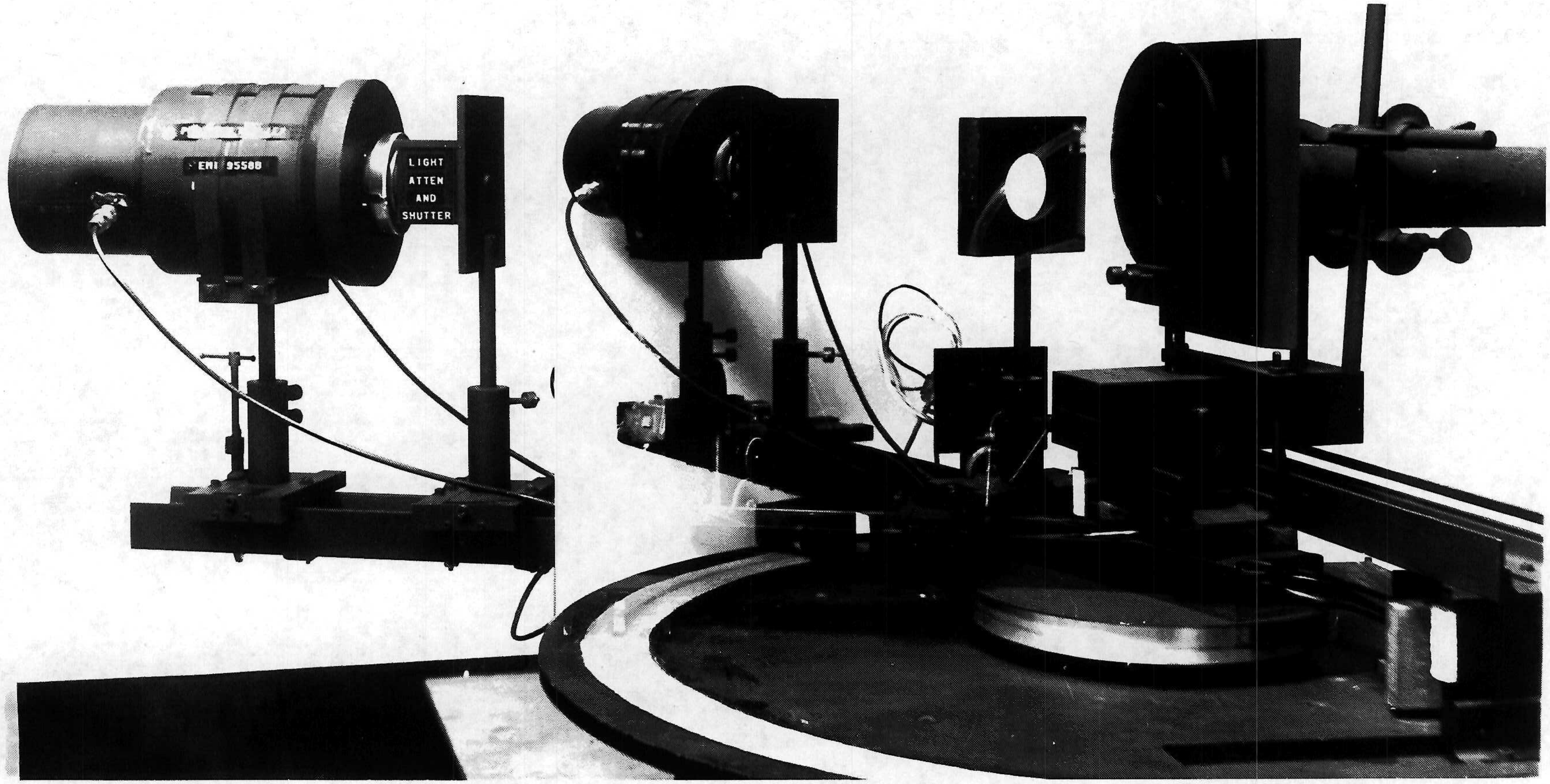

FIGURE 2

Double-Exposure of Spatial Frequency Spectrum Analyzer
Showing two Positions of the Detector During a Scan.

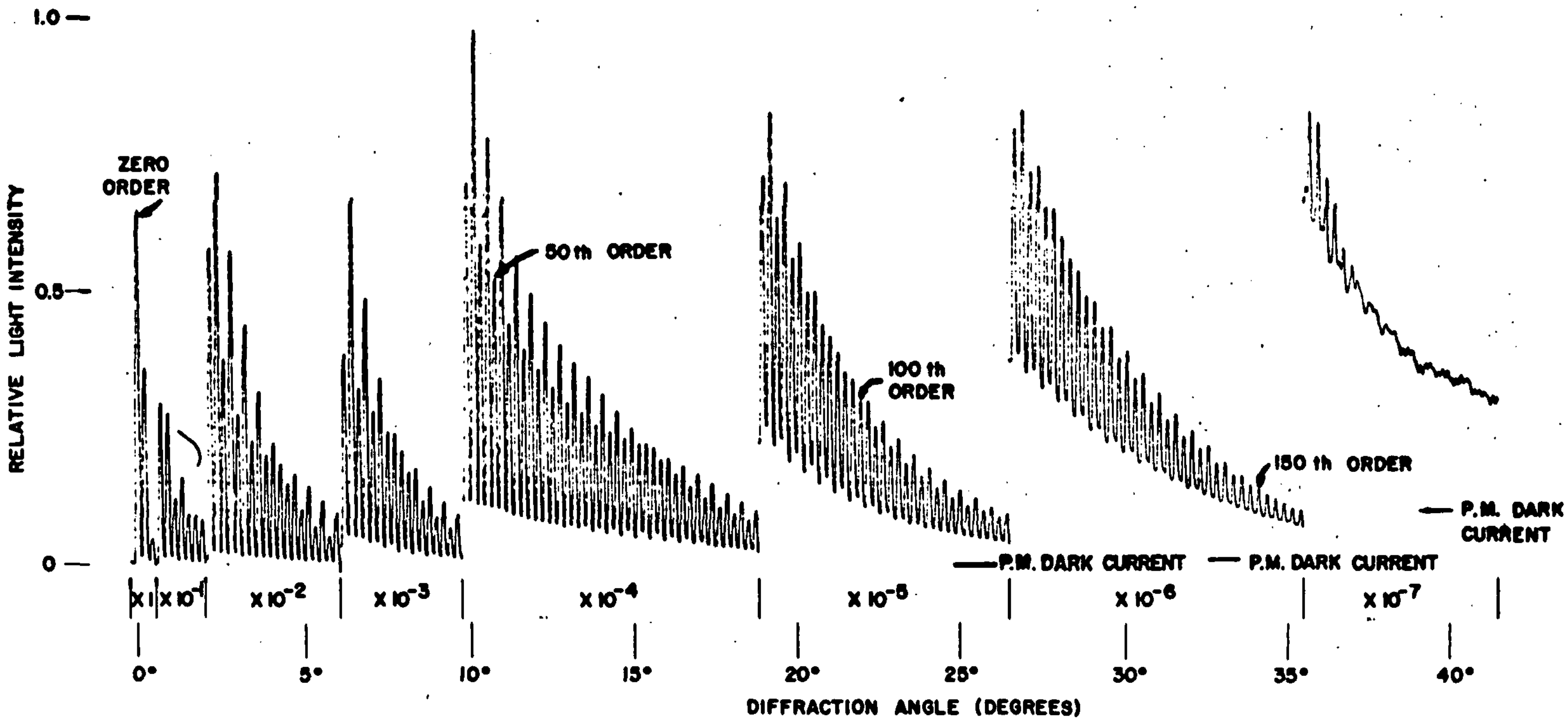

FIGURE 3

Spatial Frequency Spectrum of a 150 Lines Per Inch Ronchi Ruling

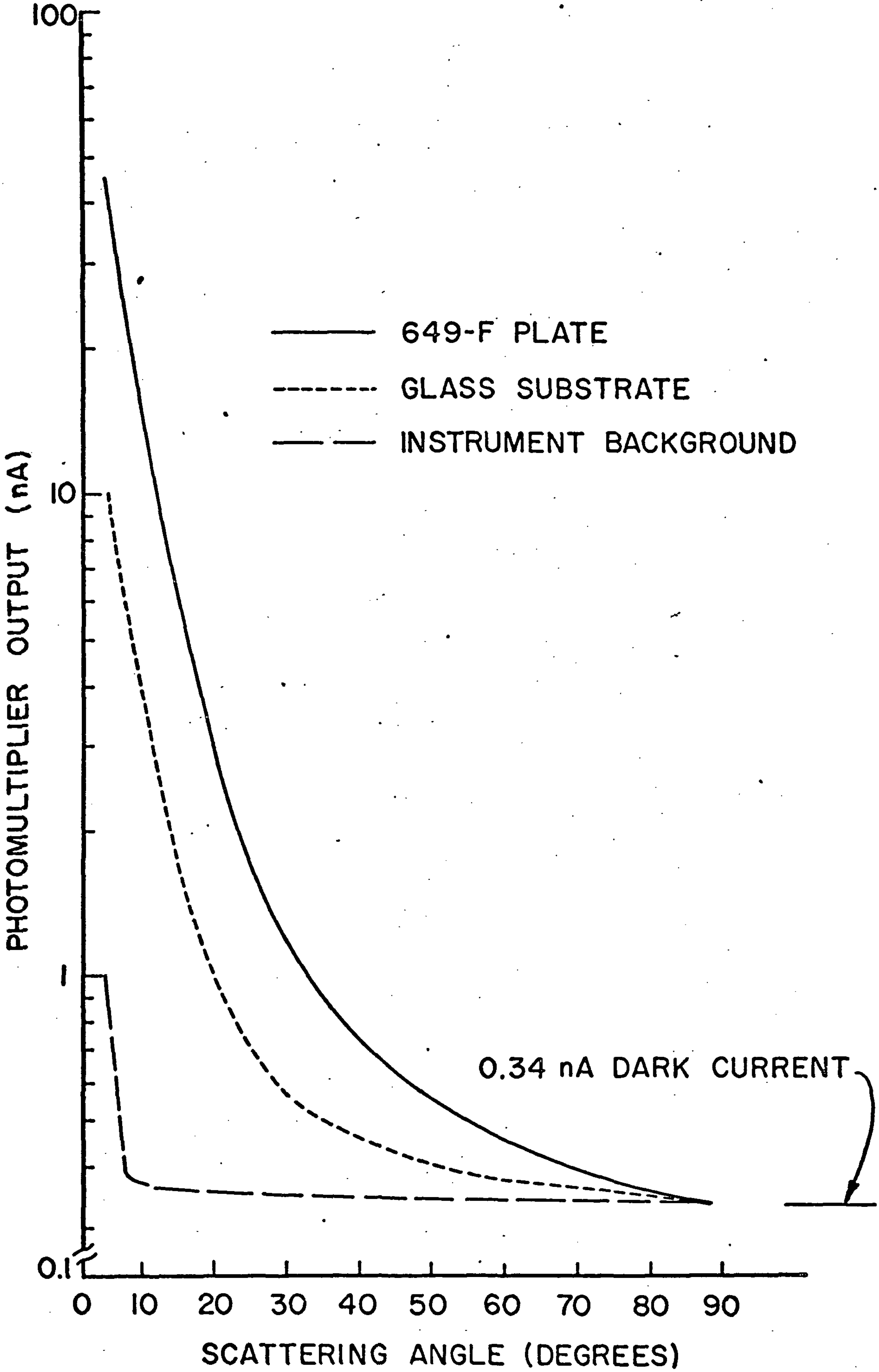

Figure 4

Scattering Spectra of Kodak 649-F Photographic Plate and Glass Substrate

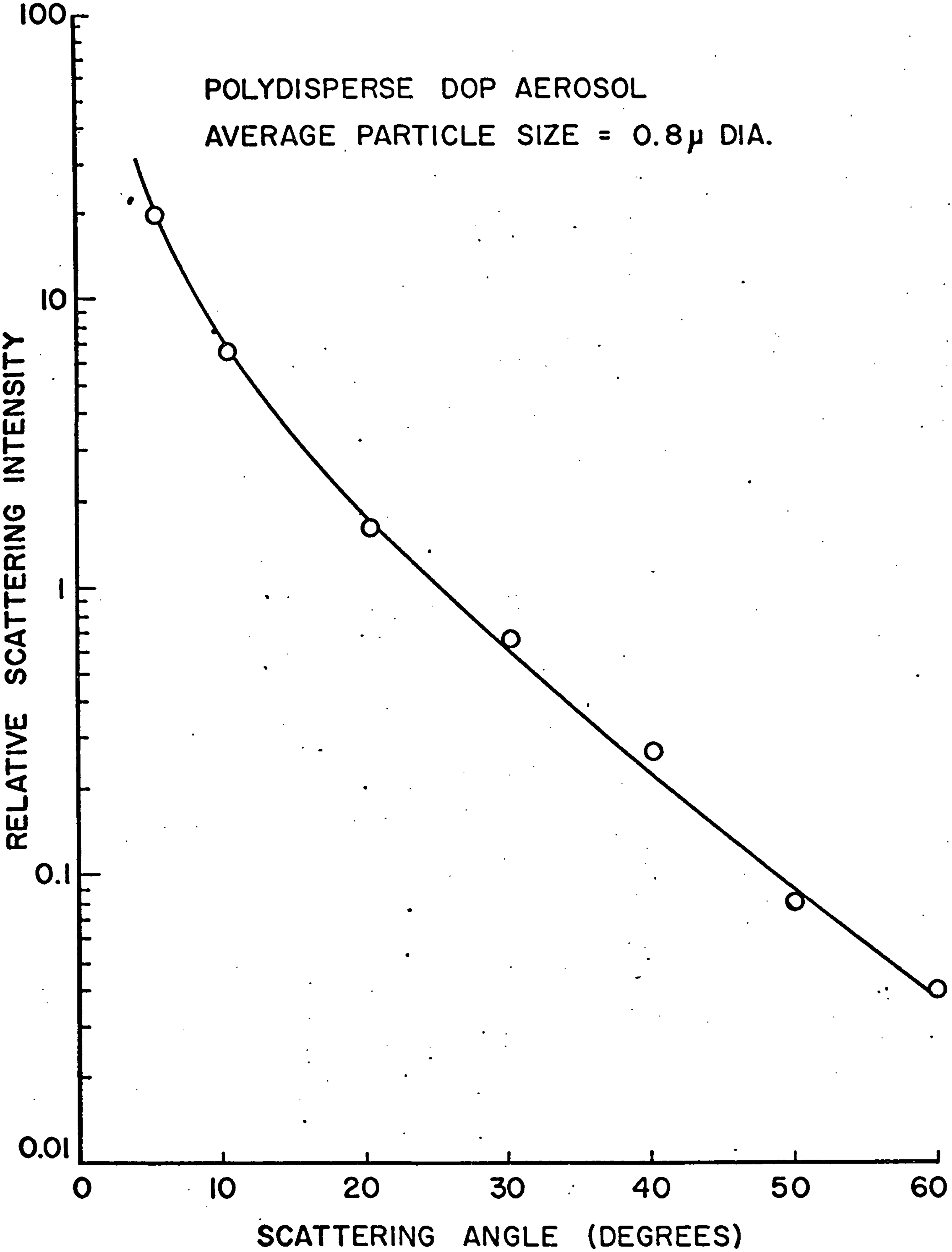

FIGURE 5

Scattering fron Polydisperse Submicron DOP Aerosol