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# PARTICLE PHASE FUNCTION MEASUREMENTS BY A NEW FIBER ARRAY NEPHELOMETER: FAN I

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## ABSTRACT

A fiber array polar nephelometer of advanced design, the FAN I is capable of in-situ phase function measurements of scattered light from man-made or natural atmospheric particles. The scattered light is measured at 100 different angles throughout 360 degrees, thus providing a potential measurement of the asymmetry of irregularly shaped particles. Phase functions can be measured at 10 to 100 Hz rates and the range of measurable single particle sizes is from 5μm to as large as 8mm. For particles smaller than 5μm the ensemble average can be measured. The FAN I is microprocessor controlled and the data may be stored on floppy disk or printed out in tabular and/or graphical form. The optical head may be separated from the computer system for operation in field or adverse conditions.

Examples of laboratory measured scattering phase functions obtained with the FAN I for spherical particles is given to illustrate its measurement capabilities.


## I. INTRODUCTION

The FAN I polar nephelometer is an atmospheric particle characterization system of advanced design. It is designed to measure, in situ, light scattered by atmospheric particles such as snow crystals and was initially developed for that purpose. The scattered light is measured at 100 different locations around a full 360 degree scattering direction at sample rates which can be set between 10 and 100 Hz. In its most sensitive mode of operation, the instrument can respond to single particles as small as 5μm diameter spheres or in its least sensitive mode it can respond to particles having maximum dimensions of approximately 8mm. The FAN I is controlled by a microprocessor, and the acquired data is permanently stored on floppy disks. Hardcopy of the data is provided by a computer printer with graphics capability. Software is supplied with the system for setup, calibration, and data display. The optical head can be separated from the computer system by 30 m or more for operation in adverse environments.

A description of the instrument is presented in Section II. In Section III is a comparison of measurements with theoretical calculations for glass beads. Section IV contains the conclusion.

## II. FAN I DESCRIPTION

### A. Optical System

A schematic of the optical head and associated electronics is provided in Figure 1. A corresponding photograph of the system with its protective covers removed is shown in Figure 2. A 5mW HeNe laser is the light source for the instrument. The system operator can adjust the output beam size from the laser's nominal 0.8mm beam size (which would be used for maximum instrument sensitivity and forward scatter angular resolution) to either 2.4mm or 8.0mm beam diameter [as measured to the exp(-2) intensity contour] using 3X or 10X beam expanders which screw directly into the output end of the laser. After leaving the beam expander, the output laser power is sampled during each sampling cycle for the phase function. This measurement will allow the system operator to make absolute radiometric scattered light measurements should he so choose. After leaving the input beam sampling system, the laser beam is transmitted across the 30.5cm diameter in situ sampling section. The beam is then reflected into a detection system which can be used to measure transmission across the sampling section. Scattered light is collected in a plane centered about the beam in which 100 gradient index lenses have been placed in a circle of constant radius. The lenses have fields of view of approximately 1 degree. Beginning at the transmission detector, which is defined as the position of zero scatter angle, and proceeding counterclockwise, the first collecting lens is placed at a 1.5 degree scatter angle, followed by 11 lenses spaced at 1.5 degree intervals up to 18 degrees. Next, lenses are placed at 5 degree intervals from 20 to 165 degrees and then at 1.5 degree intervals from 167.5 to 176.5 degrees. Using this arrangement, increased resolution is obtained in the forward and backscatter directions. The lens array between 180 and 360 degrees follows that for 0 to 180 degrees. (See Figure 3 for forward scatter positions.)

Scattered light collected by the gradient index lenses is transmitted to the Output Array Block by optical fibers as indicated in Figure 1. The scattered light outputs from the fibers are imaged to a 1024 element detector array. Only every third detector in the array is used in the FAN I. Because the detector elements must be precisely aligned with the elements of the output array block, the array is mounted on a two-dimensional micropositioner that is used to initially align the array during construction. The entire detection system is housed in a self-contained box which is shock-mounted in the main optics housing. Also included in the main housing is the instrument control and signal processing electronics and a data buffer computer memory as well as the laser power supply. Besides making this part of the FAN I capable of operating in a stand-alone mode, the electronics provide sufficient heating for the optical head during cold weather operation.

### B. Signal Processing Electronics

The signal processing electronics begins at the detector array. The detector array is a two-dimensional serially scanned optical sensor array consisting of 1024 silicon photodiodes in a 32 x 32 matrix. The detector elements are located on 100μm centers. The detector element outputs are scanned at a nominal rate of between 10 and 100 Hz which is set by the system operator. During the time between detector scans, the outputs from the detectors are capacitively stored thus effectively integrating the signal between scans. The scan rate therefore sets the integration time for the detectors. Signal integration is used to achieve high signal-to-noise ratios from low levels of scattered light. The detector elements have solid state reliability for rugged field applications and the elements have fast recovery times after reaching saturation.

The detector array and integrating electronics are controlled by a Z80 microprocessor. The microprocessor is used to control the diode sample rate and the 'frame rate' or the rate at which the array is periodically sampled. Scattering conditions and instrument setup parameters are controlled from a computer terminal by the system operator. As the detector scan begins, the detector elements are sampled serially into a 12 bit analog to digital converter. The first element sampled corresponds to the scatter magnitude at 90 degrees. A threshold comparator circuit is used to determine if sufficient signal exists from a particular scan to save the data. The signal level threshold is set by the system operator and can be one of 256 different levels. If the signal output at 90 degrees is below the designated threshold level, the array output is dumped and the detector array is reset to acquire data. When the required threshold is exceeded, the detector outputs are stored in a buffer memory configured on the Z80 microprocessor. If the data acquisition system is ready to receive data, the buffer memory immediately transmits the acquired scan to the data acquisition memory which is much larger than the Z80 memory. The data acquisition memory has been given software instructions on how to accumulate the data and store the data in floppy disk files for post experiment analysis. Should the data acquisition memory be busy at the time the buffer memory has acquired a scan, the buffer memory can acquire as many as 128 scans of data before it becomes full and must be unloaded before data acquisition can continue. The buffer memory thus allows considerable flexibility in how the data are acquired and stored, and allows the user many options in system operation that would not be possible otherwise.

C. Data Acquisition System

The data acquisition system supplied with the FAN I polar nephelometer consists of a computer terminal, a computer printer with graphics capability, and a microcomputer having 256K of RAM, and two 8 inch diameter floppy disk drives. The computer memory can be expanded to 1Mb. A 12 slot card cage is provided with the computer to allow ease of memory expansion and the inclusion of specialized hardware should the need arise. 'C' software is used in the data reduction routines. It is a language particularly suited to the polar nephelometer since one of its major uses is in the manipulation of data arrays.

Supplied with the data acquisition system is basic data reduction software. The basic function of the data reduction software is to average the recorded scans according to the user defined groupings or ensembles and display the phase function data as plots and/or listings.

Calibration and weighting factors may be applied to the raw data. Provisions are made for creating averaged background scans and subtracting them from the raw data. Every scan may be reduced individually or ensembles can be created which reduce as much as the entire data file onto one plot. Ensemble averaging is done on an angle by angle basis very much like a multichannel analyzer. In principle, the multiple scan ensemble reduction represents a second integration of the data. The first integration occurs at the signal detector and represents the integration of the scattered light as a particle passes through the incident beam. This integration should represent a single orientation of an asymmetric particle. The second integration should represent an integration over numerous particle orientations assuming that the particles are randomly oriented as they pass through the incident laser beam. The data in the histogram are displayed in a typical phase function format where relative histogram magnitudes are displayed as a function of angle. With the FAN I, however, it must be recalled that the full 360 degree scatter angle is recorded. It should be expected that for asymmetric particles, the 0 to 180 phase function will not be congruent with the 360 to 180 degree phase function. Differences in the two phase functions should reflect particle asymmetry. Therefore, the two halves of the full 360 degree phase function are displayed separately for the user's convenience.

## III. PERFORMANCE

In order to check the performance of the FAN I, spherical particles of known refractive index and diameter (range) were dropped through the scattering volume. These results were then compared with Mie scattering calculation results for single particles. Figures 4, 5, and 6 show the results for 58, 193, and 650μm beads and the theoretical calculations. The scale factor of the calculations has been adjusted to make them coincide with the measurements. The difference in scattering between the 0 to 180 and 360 to 180 measurements can be attributed to the assymetry and imperfections of the beads, within the limit of the measurement errors. Figure 7 shows a slightly different representation of the same data as in Figure 4 for the 58μm beads. Here the data has been plotted with equal spacing between the data points which emphasizes the forward and backward scattering resolution.

## IV. CONCLUSIONS

The FAN I is a state-of-the-art instrument capable of measuring the relative scattering intensities throughout 360 degrees. We have shown the results of measurements for spherical (or nearly so) particles and have compared them to Mie calculations and shown good agreement.

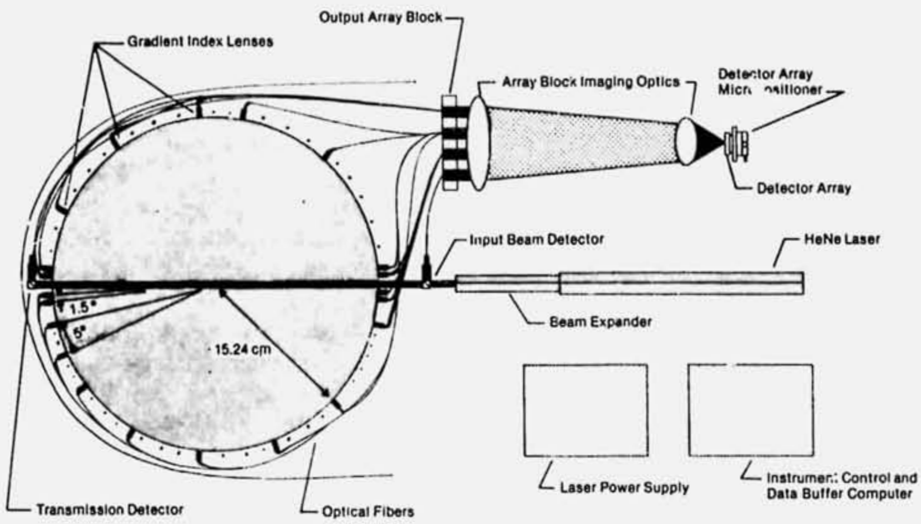


Figure 1. Schematic of optical arrangement of FAN I nephelometer.

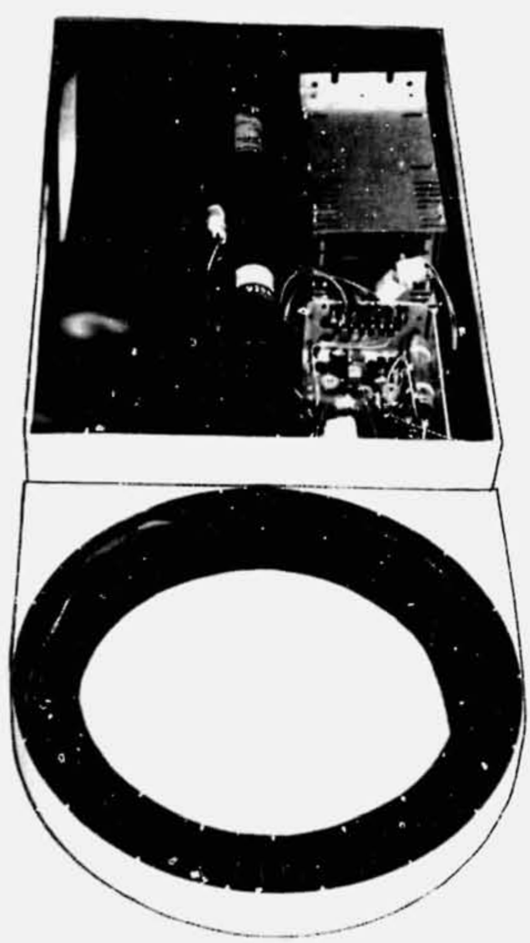

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Figure 2. Photograph of FAN I nephelometer optical system.

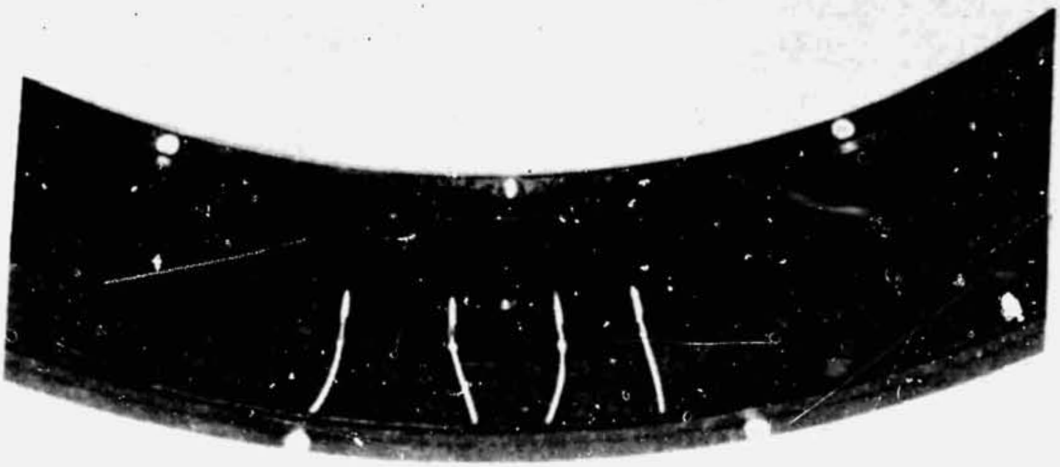

Figure 3. Forward scattering lens positions for FAN I nephelometer.