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Research Translation

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Measurement of the Size Spectrum of Cloud and Fog Particles

A. E. MIKIROV

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TRANSLATION OF

MEASUREMENT OF THE SIZE SPECTRUM OF CLOUD AND FOG PARTICLES

(Ob izmerenii spektra raspredeleniia chastits v oblakakh i tumanakh)

by

A. E. Mikirov

Akademiia Nauk SSSR, Izvestiia, Seriia Geofizicheskaia, No. 4: 512-515, 1957.

This translation has been made by the American Meteorological Society under Contract AF 19(628)-3880, through the support and sponsorship of the

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OFFICE OF AEROSPACE RESEARCH

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1. "Measurement of the size spectrum of cloud and fog particles"

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3. Mikirov, A. E. Akademiia Nauk SSSR, Izvestiia, Seriia Geofizicheskaia, No. 4: 512-515, 1957.

4. 7 typewritten pages

5. Date of translation: March 1964

6. Translator: David Kraus

7. Translated for Air Force Cambridge Research Laboratories, Office of Aerospace Research, United States Air Force, L. G. Hanscom Field, Bedford, Massachusetts, by the American Meteorological Society, Contract number AF 19(628)-3880.

8. Unclassified

9. Complete

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Summary

We describe a photoelectric method of measuring the size distribution of particles in clouds and fogs. This method is based on efficient use of the scattering function of spherical transparent particles. We tested and rated the method under laboratory conditions. We give the results of measurements of the size spectrum of particles under natural conditions.

At present there are various methods for studying the distribution of particles in clouds and fogs. The most widely used is photomicrography.

Photomicrography, which is used in various modifications, has been described in detail in [1] and we will not dwell on it here: We will point out merely that it is very cumbersome and laborious. This led us to seek other methods of solving the problem.

Employing analyses of the laboratory studies conducted in 1952-1953 with the PRZS*), we showed the possibility of developing a photoelectric method for measuring the particle size distribution of liquid aerosols 2 μ and more in diameter [2]. The essence of the proposed photoelectric method is the use of the dark field method in combination with efficient use of the scattering function.

The optical system, consisting of a light source, condenser C_1, diaphragm D_1, lens L_2, and diaphragm D_2 (see fig. 1), forms a parallel beam of light of the required

*) In reading [2], I was unable to determine the precise meaning of PRZS, but I believe the initials in Russian stand for Airborne Charge Distribution Apparatus for Field Measurements [Tr. note].

diameter. This beam passes through the space to be investigated and is cut off by black screen S, behind which is the cathode of the photomultiplier. When there are no particles in the light flux, the light is cut off by the dark screen and does not reach the photocathode.

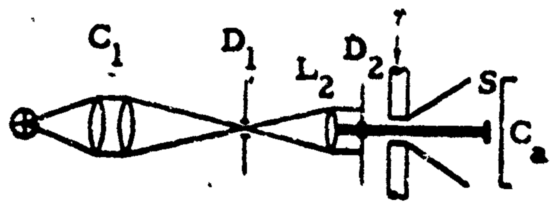

Figure 1

Tube T, through which the aerosol is drawn, is mounted perpendicular to the direction of the light flux. The particles passing along the tube enter the light beam. The light scattered by the particles strikes the photocathode, and, as a result, a voltage pulse, whose amplitude is a function of the particle size, appears at the output. The voltage pulses produced at the output of the photomultiplier are fed to a wind-band amplifier, whose output is hooked up to a 6-channel amplitude analyzer.

Let us determine how efficiently the scattering function is employed in this system, i.e., what part of the light scattered by the particles strikes the photocathode. For simplicity's sake, let us assume that the particle is large and that the scattering function may be examined as a superposition of geometric and diffraction patterns. The amount of light scattered by the particles and directed into a cone with a linear angle β is [3]

$$I = I_1 + I_2 = \int_0^\beta F(\beta)\,d\beta + \int_0^\beta \Phi(\beta)\,d\beta,$$

where

$$F(\beta) = \frac{\rho^2}{8}\tau(\beta); \text{ here } \rho = \frac{2\pi r}{\lambda},$$

$$\Phi(\beta) = \frac{\rho^4}{2}(1+\cos\beta)^2\frac{[J_1(\rho\sin\beta)]^2}{\rho^2\sin\beta^2}.$$

We give the values of $\int_0^\beta F(\beta)d\beta$ in fractions of πr^2.
From the table it is evident that 94.4% of the light striking the particle is sent forward in all directions ($\beta = 90^\circ$) and 5.6% is sent backward.

β	$\int_0^\beta F(\beta)d\beta$	β	$\int_0^\beta F(\beta)d\beta$	β	$\int_0^\beta F(\beta)d\beta$
0	0,10[illegible]	60	0,914	120	0,251
10	0,118	70	0,934	130	0,957
20	0,365	80	0,940	140	0,969
30	0,597	40	0,944		
40	0,763	100	0,046		
50	0,864	110	0,948	180	1,000

Even if we take an angle of only 40 to 50°, 76.3 to 86.4% of the light incident on the particle will be used. This shows that the system makes efficient use of the scattering function and, consequently, insures sufficient sensitivity, since practically all the light scatte·ed by the particles is· sent forward and strikes the photocathode.

Evidently the amount of diaphragmed light striking the photocathode is

$$I_2 = \int_0^\beta \Phi(\beta)\,d\beta - \int_0^{\beta_1} \Phi(\beta)\,d\beta,$$

where β_1 is the angle cut off by the black screen. For photometric purposes, the dimension of the screen was chosen such that $\beta_1 = 3^\circ$.

From calculations, one may construct the theoretical relationship between the particle size and the amount of light incident on the photocathode and, since the photomultiplier operates on a linear system, one may also calculate the relationship between the particle size and the pulse.

The curve in fig. 2 shows the theoretically calculated relationship between the particle size and the amount of light incident on the photocathode. The angle of efficiency of the scattering function was taken as 40° in our case.

Elementary quantitative calculation shows that the following apparatus may be used to measure particle diameters beginning at 2 μ: a photomultiplier of the FEU-19 type, having a sensitivity of the order of 25 a/lu with a dark current of 0.5×10^{-9} a (sensitivity 1 a/lu), a 12 candle-power light source, and employment of the light within an angle $\beta = 40°$ of the scattering function.

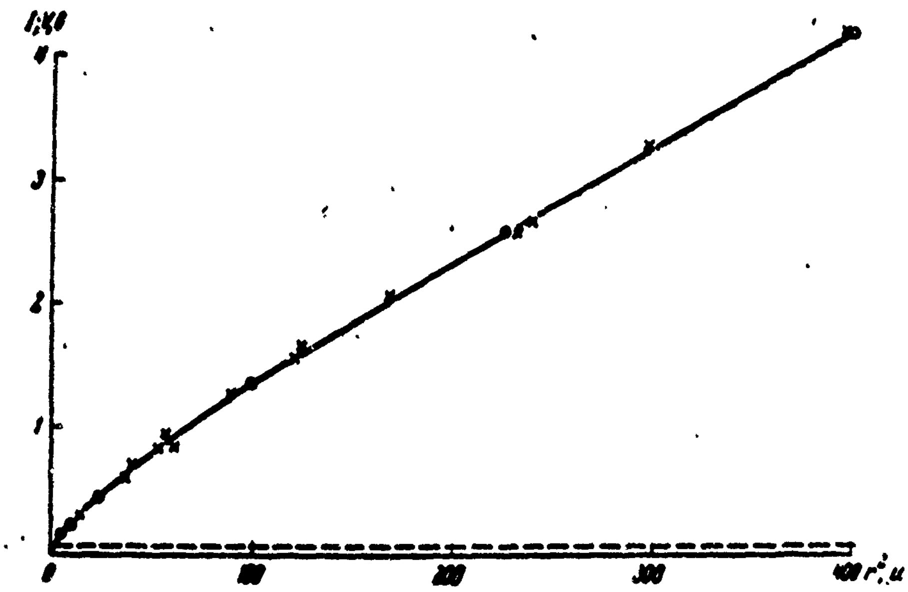

Figure 2

One of the essential characteristics of the instrument is its resolution, which is a function of the size of the effective area of the light field. Assuming a Poisson distribution of particles and clouds, one may show that when $NV \leq 0.35$, there is a 0.05 probability that not more than one particle will be present in the light field at one time (N is the number of particles in a unit volume, and V is the effective region of the light field).

Since there are not more than 10^3 particles/cm^3 in natural clouds and fogs, we chose the effective area of the light field such that we would have a resolution of 10^2 to 10^4 particles/cm^3 using diaphragm D_2. It should be noted that one of the main difficulties in developing this type of instrument is the calibration. For this purpose, the particles are passed through the instrument and settle on a glass slide. The exposure was selected such that not more than 2 particles would precipitate onto the slide. The pulse supplied by the particle was measured with a cathode oscillograph and the particle size was determined photomicrographically. One cannot avoid errors resulting from evaporation when water particles are used for the calibration. Since a transparent sphere has a real index of refraction, in this case there will be no absoprtion and the attenuation factor should coincide with the scattering coefficient. A comparison of the curves of H. G. Houghton and J. A. Stratton [4] with those of A. R. Vol'pert and A. N. Potekhin [5], shown in figs. 3 and 4, indicates that the scattering functions of water particles and oil particles are identical at particle sizes $\geq 4\ \mu$. With this in mind, we conducted our calibration with oil particles and the results are shown in fig. 2. The noise level values are shown by the dashed line in fig. 2.

The agreement of the experimental data with the theoretical calculations indicates K. S. Shifrin's [3] formulas describe the scattering function of the particles with sufficient accuracy. The calibration curve showe that the apparatus may measure particle sizes beginning at 2 μ in diameter.

Field tests of the apparatus were conducted on Mount Elbrus. The results of measurements of particle size distribution in natural clouds were positive. Particle size distribution measurements were made in several clouds in calm weather. The measurements were made at an altitude of 3050 m at 5-min intervals; the actual spectrum measurement took 20 seconds.

Figures 5 and 6 show the particle-size spectra for two clouds which formed as a result of an ascending air current and the fall of precipitation on the Azau valley;

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