NASA TECH BRIEF

NASA Pasadena Office

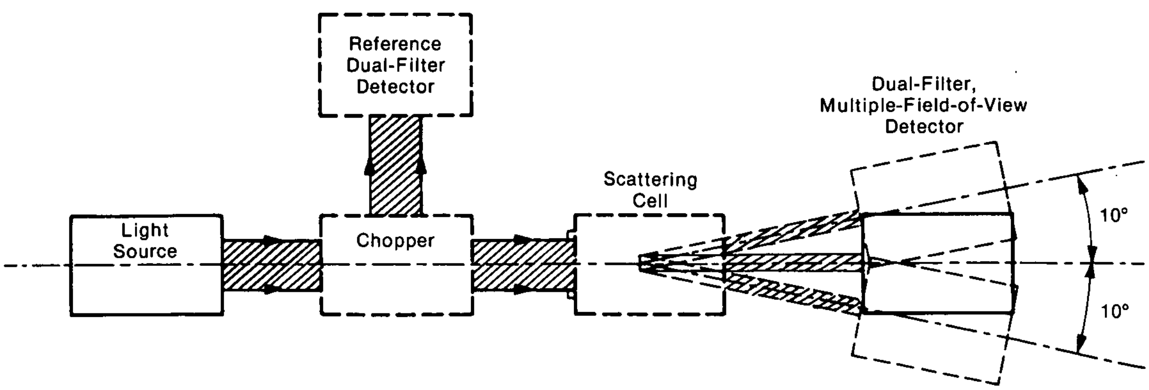
NASA Tech Briefs announce new technology derived from the U.S. space program. They are issued to encourage commercial application. Tech Briefs are available on a subscription basis from the National Technical Information Service, Springfield, Virginia 22151. Requests for individual copies or questions relating to the Tech Brief program may be directed to the Technology Utilization Office, NASA, Code KT, Washington, D.C. 20546.

Developments in Spectrophotometry III: Multiple-Field-of-View Spectrometer To Determine Particle-Size Distribution and Refractive Index

The multiple-field-of-view spectrometer/refractometer has many similarities to the instrument described in NASA Tech Brief B75-10333, in that it overcomes the problems associated with taking representative samples from a medium, and it is considerably more accurate than other available remote-measurement instruments. However, although this instrument is also based on an inverse solution to the equations for light scattered by a transparent medium, measurements are taken over several angles of incidence rather than over several frequencies. This allows a single instrument to be used for a two-step process: one series of angular measurements at a single frequency to determine particle-size distribution, and a second series of angular measurements at a second single frequency to determine the refractive index of the sample. These measurements can be used to simultaneously determine chemical and physical properties of particles in a mixed gas or liquid.

The instrument is used to analyze light scattered by the suspended particles. The way in which particles scatter light can depend upon the properties of the light (its intensity and wavelength) and the properties of the particles (their geometry, location, sizes, and composition-related properties such as refractive index). In theory, if the incident light is known and if the scattered light is measured, one should be able to calculate the properties of the scattering medium. This new instrument is made possible by the discovery of a way to separate the effects of the two scattering-medium properties (particle size and refractive index).

The scattering is measured over several angles at two carefully selected wavelengths. One wavelength, λ_1, is chosen so that the scattering depends only on the size distribution of the particles and not on their composition; scattering at the second wavelength, λ_2, depends on both the particle sizes and their indices of refraction. Thus, measurements are made at λ_1, and the particle distribution (in equivalent spheres) is calculated. This information, along with measurements at λ_2, is used to calculate the indices of refraction. Accuracy is insured by confining the angle over which the scattered light is measured (±7.5° is best) and by using sufficiently-small angular increments (less than 15 arc minutes).



Dual-Frequency, Multiple-Field-of-View, Particle-Size Spectrometer and Refractometer

(continued overleaf)

This document was prepared under the sponsorship of the National Aeronautics and Space Administration. Neither the United States Government nor any person acting on behalf of the United States Government assumes any liability resulting from the use of the information contained in this document, or warrants that such use will be free from privately owned rights.

A block diagram of the system is illustrated. The light source can be the Sun or a laboratory source (in which case a chopper is used to divert some incident light to a reference detector). The measured medium can be in a sample cell, or it can be suspended in the air or a liquid. The detectors have two filters, one for measuring each of the wavelengths, λ_1 and λ_2. The object detector can be moved to measure the scattered light over an angle of ±10°.

The wavelength λ_1 is chosen such that its ratio to the circumference of the smallest particle expected in the sample be much smaller than unity. It has been discovered that when λ fulfills this criterion and the scattering angle is less than ±10°, the scattering of a distribution of particles is described by the Fraunhofer diffraction theory. In this theory the scattering is treated as though it occurs at a hole in the plane screen. The intensity of the scattered light, I_S, is not dependent on the composition of the particles but only on their size distribution, n(r), as in the following relationship:

$$I_S = f_1[I_0, \lambda_1, \Theta_S, n(r)]$$

That is, the scattering intensity (I_S) is a function of the initial intensity (I_0), the wavelength (λ_1), the scattering angle (Θ_S), and the particle-size distribution. The actual form of the function is an integral equation, and by finding an analytical solution for the equation with n(r) as the dependent variable,

$$n(r) = g(I_S, \lambda_1, \Theta_S, I_0)$$

it was possible to design the spectrometer to measure n(r) by varying the angle Θ_S and using λ_1 as defined above.

The measurement of the index of refraction requires a wavelength, λ_2, which is larger than λ_1 and statistically independent of it. Here the more general Mie theory of scattering by conducting spheres applies, and I_S also depends on the index of refraction (a complex number with two parts: m_r and m_i).

$$I_S \equiv f_2[I_0, \lambda_2, \Theta_S, n(r), m_r, m_i]$$

However, n(r) is known, and m_r and m_i are the only unknowns in this relationship. Since the values of m_i and m_r are independent, a closed solution is not possible, and an iterative procedure must be used. A guess is made for the values of m_r and m_i, the refractive index terms, and it is used to calculate a hypothetical observed scattering intensity, I_S. This is done for each angle Θ_S.

Successive values for m_i and m_r are tried until a I_S sufficiently close to the measured I_S is found. These values of the components of the refractive index will be correct within experimental error. The technique used to find the best value of m_r and m_i is an improvement over classical methods and is described in NASA Tech Brief B75-10335.

Notes:

1. Further discussion may be found in "Determination of Atmospheric Particle Size Distribution From Forward Scattering Data," by A. L. Fymat in Monitoring of Terrestrial Environment from Space, ed. Rassegna, Rome, Italy, vol. 13, March 1974, p. 185.
2. Other recent developments in spectrophotometry that may be of interest to readers of this Tech Brief are found in:
   a. NASA Tech Brief B75-10332, Developments in Spectrophotometry I: An Instrument for High-Resolution Measurement of Optical Intensity and Polarization
   b. NASA Tech Brief B75-10333, Developments in Spectrophotometry II: A Multiple-Frequency Particle-Size Spectrometer
   c. NASA Tech Brief B75-10338, Minimization Search Method For Data Inversion
3. Requests for further information may be directed to:

   Technology Utilization Officer
   NASA Pasadena Office
   4800 Oak Grove Drive
   Pasadena, California 91103
   Reference: TSP75-10335

Patent status:

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its development should be addressed to:

Patent Counsel
NASA Pasadena Office
4800 Oak Grove Drive
Pasadena, California 91103

Source: Alain L. Fymat of
Caltech/JPL
(NPO-13614)

Categories: 03 (Physical Sciences)
04 (Materials)
02 (Electronics Systems)