

Specific Scattering by Uniform Minerogenic Suspensions

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Abstract

The Mie theory has been applied to determine the theoretical scattering from 1 mg per liter concentrations of uniformly-sized spherical particles over the size range from very small particles up to particles with a radius of 6 microns. The theoretical results compare favorably with experimental results recently published by Jerlov and Kullenberg.

JERLOV and KULLENBERG (1953) have published the results of laboratory measurements of the Tyndall effect of uniformly-sized suspensions of quartz and feldspar particles. Their results are presented in terms of the scattering coefficient, s (km^{-1}), for suspensions with particle diameters of 1, 3, 7, 9, and 12 microns with known concentrations of suspended material. Their coefficient, s , takes into account the effects of suspended materials only. The following empirical relationship was used to convert the Tyndall reading, A , to scattering, s (JERLOV, 1953):

$$s \text{ (km}^{-1}\text{)} = 0.52 A - 3 \quad (1)$$

The Mie theory (GUMPRECHT and SLIEPCEVICH, 1951, 1953a, 1953b) can be used to determine the theoretical value of the scattering coefficient for suspensions of the type employed by Jerlov and Kullenberg. It seems worthwhile to compare the theoretical results as predicted by the Mie theory to those obtained experimentally in order to use the theory to predict what would occur over a more complete range of particle sizes.

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The Mie theory requires the use of the effective area coefficient, K , which is defined as the ratio between the effective scattering cross section and the geometric cross section of a spherical particle. It is computed as a function of the dimensionless parameter, $\alpha = 2\pi r/\lambda$, and the relative refractive index, m , between the particle and the suspending medium, in this case water. The particle radius is r and λ is the wave length of the light energy that is being scattered. GUMPRECHT and SLIEPCEVICH (1951) tabulate K as a function of α for several values of m equal to and greater than 1.20. In addition, VAN DE HULST (1946) provides an equation for determining K for values of m near 1.00. The above tables and equation provide sufficient information to interpolate for K as a function of α for values of m between 1.00 and 1.20.

Considering the effects of scattering only, the theoretical extinction, H , due to uniformly-sized spherical particles is then:

$$H = K\pi r^2 n \quad (2)$$

where n is the number of particles per unit volume. Equation (2) applies for particles with the same relative refractive index for light of a single wave length.

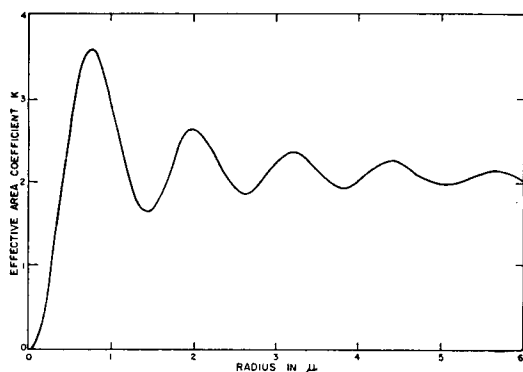


Fig. 1. Mie scattering curve for material with a relative refractive index of 1.15 for blue light (0.470μ). Adapted from Gumprecht and Sliepcevich (1953a) and Van de Hulst (1946).

The specific scattering is now defined as the extinction per meter, H_0 , for a suspension containing 1 mg of suspended material per liter. If the material in suspension has the usually assigned average density of minerals of 2.65, the suspension will contain $0.377 \times 10^{-6} \text{ m}^3$ of suspended material per m^3 of suspension. Equation (2) can then be rewritten

$$H_0 = \frac{3}{4} \frac{K}{r} \left(\frac{4}{3} \pi r^3 n \right) = \frac{3}{4} \frac{K}{r} (0.377 \times 10^{-6}) \quad (3)$$

Taking the length unit for the radius in the conventional unit of the micron, equation (3) becomes:

$$H_0 = 0.283 K/r \quad (4)$$

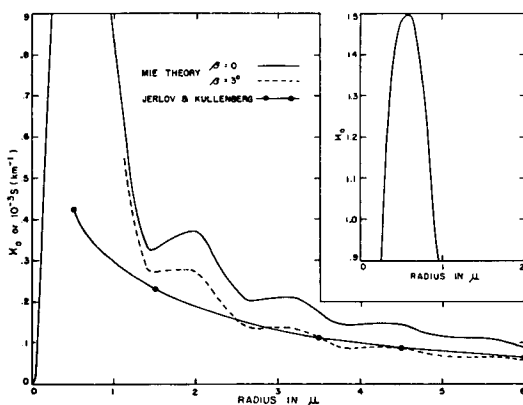


Fig. 2. Theoretical and experimental (Jerlov and Kullenberg, 1953) specific scattering for concentrations of suspended materials of 1 mg per liter.

Jerlov and Kullenberg used quartz and feldspar with relative refractive indices of approximately 1.15. Figure 1 shows the theoretical variation of K , the effective area coefficient, with the radius, r , for spherical particles with relative refractive indices of 1.15 for blue light (0.470μ).

Figure 2 shows the theoretical specific scattering computed from equation (4) and the material presented in figure 1. Whenever these theoretical scattering computations are compared to actual measured values of scattering, a correction should be made to the theoretical computations to take into account the fact that any practical measuring device measures light which is scattered in a nearly forward direction as transmitted light (GUMPRECHT and SLIEPCEVICH, 1953a). The dashed curve on figure 2 shows the theoretical scattering corrected to exclude light scattered into a cone of half angle β centered about the forward direction. The correction decreases with decreasing particle size until it becomes relatively unimportant for small values of β for particles with radii below approximately 1 micron.

The experimental results for specific scattering from JERLOV and KULLENBERG (1953) are also shown on figure 2. Considering the fact that their material was made up of non-spherical particles, the agreement between theory and measurement is striking for all but the smallest-sized particles, particularly if the measurements are compared to the theoretical curve corrected to exclude a part of the nearly forward scattered light.

The large discrepancy between the theoretical specific scattering and the measured specific scattering for the smallest-sized particles with a nominal radius of $1/2$ micron is probably due to a combination of the following factors: (a) failure of some of the assumptions, such as the assigned values of the refractive index or the density or the effects of non-spherical particles, in applying the Mie theory; (b) small experimental errors in determining the particle size and concentration down in the size range where Stokes' law becomes increasingly difficult to apply; or (c) the fact that the slope constant in equation (1) cannot be assumed to be a constant over the whole range of particle sizes.

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