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LINEAR KINETIC THEORY AND PARTICLE TRANSPORT IN STOCHASTIC MIXTURES

Progress Report

for the period

6/15/93 - 3/21/94

and

Request for Second Year Funding

for the period

6/15/94 - 6/14/95

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PUBLICATIONS RESULTING FROM THIS GRANT AND SUMMARY OF RESULTS TO DATE

The primary goal in this research is to develop a comprehensive theory of linear transport/kinetic theory in a stochastic mixture of solids and immiscible fluids. The statistics considered correspond to N-state discrete random variables for the interaction coefficients and sources, with N denoting the number of components of the mixture. The mixing statistics studied are Markovian as well as more general statistics, such as renewal processes. A further goal of our work is to demonstrate the applicability of our formalism to real world engineering problems. This three year program was initiated June 15, 1993 and has been underway nine months. Many significant results have been obtained, both in the formalism development and in representative applications. We summarize these results by listing the archival publications resulting from this grant, including the abstracts taken directly from the papers.

1. F. Malvagi and G.C. Pomraning, "Stochastic Atmospheric Radiative Transfer," *Atmospheric and Oceanic Optics* 6, 1064 (1993). In Russian.

A radiation treatment of the broken cloud problem is described, based upon a class of stochastic models of the equation of radiative transfer, which considers the clouds and clear sky as a two component random mixture. These models, recently introduced in the kinetic theory literature, allow for both Markovian and non-Markovian statistics as well as spatial variations of the cloudiness. Numerical results are given which compare different models of stochastic radiaitve transfer, and which point out the importance of treating the broken cloud problem as a stochastic process. It is also shown that an integral Markovian model proposed within the atmospheric radiation community by Titov is equivalent to one of our differential models.

2. B. Su and G.C. Pomraning, "A Variational Approach to Stochastic Transport," *J. Quant. Spectrosc. Radiat. Transfer*, in press.

We consider the problem of radiation transport through a stochastic background material described by arbitrary statistics. A variational principle is developed to estimate the ensemble average of a general linear functional of the solution. Numerical results based upon this principle are compared with exact benchmark results using a variety of trial functions. The test problem employed is a source-free rod, in a monochromatic, time independent setting. The variational formalism is used to estimate reflection, transmission, absorption, and the intensity at the rod center for a binary background mixture of immiscible fluids. The numerical calculations employ various renewal statistics, including Markovian, to describe the mixing of the two fluid components.

3. B. Su and G.C. Pomraning, "A Stochastic Description of a Broken Cloud Field," *J. Atmos. Sci.*, in press.

We consider the chord length distributions within a cloud and between clouds. Such information is needed as input to certain statistical models of cloud-radiation interaction. Modeling the clouds as azimuthally symmetric ellipsoids, we find that the chord length distribution through a cloud of fixed size is proportional to the chord length. The proportionality constant depends upon the semi-axes of the ellipse as well as the angle of incidence of the radiation. This linear behavior is easily convolved over an arbitrary size distribution of the clouds to obtain the chord length distribution through a statistical mixture of different cloud sizes. The chord length distribution between clouds is also considered for an atmospheric layer of finite thickness. In this case, both analytic and numerical methods are needed to obtain results. In the limit of an infinite thickness atmospheric layer described by homogeneous statistics and fixed cloud chord lengths, our considerations reduce to a Markovian (exponentially distributed chord lengths) model for the inter-cloud spacing .

4. A.K. Prinja and G.C. Pomraning, "On the Propagation of a Charged Particle Beam in a Random Medium. I: Gaussian Statistics," *Transport Th. Statis. Phys.*, in press.

A model is presented for the transport of energetic charged particles in a medium whose density is a continuous random function of position. Using the straight-ahead continuous slowing down approximation and assuming Gaussian statistics for the density fluctuations, exact solutions for the ensemble-averaged flux and dose are obtained. It is demonstrated that the ensemble-averaged flux satisfies an exact closed equation of the Fokker-Planck type in energy. The effect of fluctuations is to introduce straggling in space and energy, resulting in the dose profile extending well beyond the ion range for a corresponding deterministic medium. Very reasonable results are obtained for a fluctuation amplitude on the order of the mean density, in spite of the negative densities admitted by the Gaussian process. However, for very large fluctuations, the Gaussian model leads to a considerable overestimate of the dose near the surface.

5. G. C. Pomraning and A.K. Prinja, "On the Propagation of a Charged Particle Beam in a Random Medium. II: Discrete Binary Statistics," *Transport Th. Statis. Phys.*, in press.

We consider the linear transport of energetic charged particles through a background stochastic mixture consisting of two immiscible fluids or solids. The transport model used is the continuous slowing down description in the straight-ahead approximation. Under the assumption of homogeneous Markovian mixing statistics and separable (in space and energy) stopping powers with a common energy dependence, the problem of finding the ensemble-averaged intensity and dose is reduced to simple quadrature. The use of the Liouville master equation offers an alternate approach to this problem, and leads to exact differential equations whose solution gives the ensemble-averaged intensity and dose. This master equation approach applies to inhomogeneous Markovian statistics as well as non-separable stopping powers. Both treatments can be extended, in an approximate way, to non-Markovian statistics. Typical numerical results are given, contrasting this stochastic treatment with the standard treatment which ignores the stochastic nature of the problem.

6. G.C. Pomraning and B. Su, "A Closure for Stochastic Transport Equations," *Proc. Int. Conf. Reactor Phys. Reactor Comp.*, Ben-Gurion Univ. Press, p.672, (1994).

The problem of particle transport through a stochastic mixture of two immiscible materials is considered. The material mixing process is assumed to obey Markovian statistics. An ensemble average of this stochastic transport equation leads to two equations containing four different ensemble-averaged intensities. To close these equations to a set of two equations in two unknowns, certain rod geometry problems are considered. In this geometry, two distinct exact analyses are possible, namely a small correlation length analysis, and a nonstochastic mean number of secondaries per collision analysis. The closure philosophy is to demand that the closed set of two equations reproduces these exact limiting behaviors. Numerical results are given which compare the predictions of this new closure with exact benchmark results as well as with the standard closure available in the literature.

7. B. Su and G.C. Pomraning, "Limiting Correlation Length Solutions in Stochastic Radiative Transfer," *J. Quant. Spectrosc. Radiat. Transfer*, in press.

The problem of particle transport through a Markovian stochastic mixture of two immiscible materials is considered. In the special case of rod geometry, both small and large correlation length limiting solutions are explicitly constructed. The analysis is general in the sense that independent fluctuations are allowed in both the single scatter albedo and the particle mean free path. These results are used to provide two new closures for a low order ensemble averaging of the stochastic equation of transfer. Numerical comparisons with Monte Carlo benchmark results are given to assess the accuracy of the proposed closures.

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