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INTERACTION OF ELECTROMAGNETIC RADIATION WITH BULK MATTER.(U)
AUG 76 E WOLF

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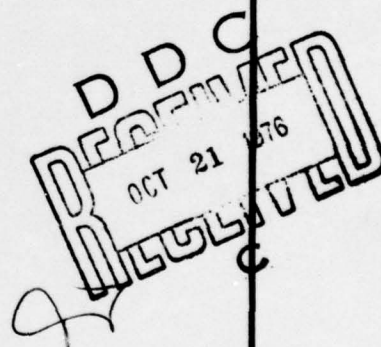
INTERACTION OF ELECTROMAGNETIC RADIATION
WITH BULK MATTER

FINAL REPORT

GRANT No. DAHC04-74-G-0014

PREPARED BY
EMIL WOLF

AUGUST 1976



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DEPARTMENT OF PHYSICS AND ASTRONOMY

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The University of Rochester
Department of Physics and Astronomy
Rochester, New York 14627

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I. INTRODUCTION

This report summarizes the research activities carried out under grant #DAHCO4-74-G-0014, during the period 8/1/1973 - 7/31/1976. The main investigations were in the area of electrodynamics of spatially dispersive media, where many new results were obtained. Initially a model medium, characterized by a dielectric response function appropriate to the neighborhood of an isolated exciton transition frequency, was considered and the medium was assumed to form a plane-parallel slab. The exact mode expansion for the electromagnetic field in such a medium was found. The solution has thrown much light on the controversial question of the so-called additional boundary conditions in non-local electrodynamics. Our later investigations extended this analysis to spatially dispersive media of other geometries and to media with more general dielectric response. Čerenkov and transition radiation in spatially dispersive media was also studied.

Substantial results were also obtained in the theory of non-relativistic quantum - mechanical scattering and resonance theory with finite-range potentials. The non-local boundary conditions of electromagnetic theory, (expressed by the so-called extinction theorem), that played an important role in our investigations of spatial dispersion, were found to have an analogue in these fields. We have shown that with the help of such a non-local boundary condition, one can define resonance states and bound states in a way that appears to have considerable advantages over other approaches. We also showed that an important formula (the so-called Kohn-Rostoker-Ziman boundary condition), frequently used in band-structure calculations in solids, is an immediate consequence of our new formulation.

I. INTRODUCTION (Cont'd)

Investigations in several other areas were also undertaken. In particular we have studied the relationship between the multipole expansion of a field generated by a localized charge - current distribution and the angular spectrum representation of the field. An important consequence of our analysis are explicit formulae for the multipole moments in terms of the radiation pattern of the field. These formulae make it possible to calculate the field at any point outside a (fictitious) sphere containing the charge - current distribution from the knowledge of the far field.

We also put forward a new theory of radiative energy transfer in free electromagnetic fields. This theory provides a model for energy transport that is rigorous both within the framework of the stochastic theory as well as within the framework of the theory of the quantized field. This theory has an important bearing on the as yet unsettled question of the relationship between the usual theory of radiative transfer and modern theories of radiation.

Full accounts of our investigations are contained in 17 papers. Titles, authors and journal references are listed on p. 3 - 4. Summaries of these papers are given on p. 5 - 11. Some of the results, obtained by a graduate Research Assistant while employed on this project, formed part of a M.S. thesis at the University of Rochester. Particulars are given in p. 12. List of personnel that assisted in this project is given on p. 13.

II. LIST OF PUBLICATIONS

1. G.S. AGARWAL: "Master Equation Methods in Quantum Optics" (Progress in Optics, ed. E. Wolf, Amsterdam, North Holland Publishing Company) Vol. XI (1973).*
2. A.J. DEVANEY and E. WOLF: "Radiating and Nonradiating Classical Current Distributions and the Fields They Generate" (Phys. Rev. D8, 1044 (1973)).
3. A.J. DEVANEY and E. WOLF: "Multipole Expansions and Plane Wave Representations of the Electromagnetic Field" (J. Math. Phys. 15, 234 (1974)).*
4. G.S. AGARWAL, D.N. PATTANAYAK and E. WOLF: "Electromagnetic Fields in Spatially Dispersive Media" (Phys. Rev. B10, 1447 (1974)).
5. J.T. FOLEY and D.N. PATTANAYAK: "Electromagnetic Scattering from a Spatially Dispersive Sphere" (Optics Comm. 12, 113 (1974)).
6. G.S. AGARWAL, D.N. PATTANAYAK and E. WOLF: "Structure of Electromagnetic Fields in Spatially Dispersive Media of Arbitrary Geometry" (Phys. Rev. B11, 1342 (1975)).
7. M.D. SRINIVAS: "Foundations of a Quantum Probability Theory" (J. Math. Phys. 16, 1672 (1975)).
8. J.T. FOLEY and A.J. DEVANEY: "Electrodynamics of Nonlocal Media" (Phys. Rev. B12, 3104 (1975)).
9. B.J. HOENDERS and D.N. PATTANAYAK: "Interaction of a Moving Charged Particle with a Spatially Dispersive Medium. I. Structure of the Electromagnetic Field" (Phys. Rev. D13, 282 (1976)).
10. B.J. HOENDERS and D.N. PATTANAYAK: "Interaction of a Moving Charged Particle with a Spatially Dispersive Medium. II. Cerenkov and Transition Radiation" (Phys. Rev. D13, 291 (1976)).
11. D.N. PATTANAYAK and E. WOLF: "Scattering States and Bound States as Solutions of the Schrodinger Equation with Nonlocal Boundary Conditions" (Phys. Rev. D13, 913 (1976)).
12. E. WOLF: "New Theory of Radiative Energy Transfer in Free Electromagnetic Fields" (Phys. Rev. D13, 869 (1976)).
13. D.N. PATTANAYAK and E. WOLF: "Resonance States as Solutions of the Schrodinger Equation with a Nonlocal Boundary Condition" (Phys. Rev. D13, 2287 (1976)).#
14. G.C. SHERMAN, J.J. STAMNES, and E. LALOR: "Asymptotic Approximations to Angular-Spectrum Representations" (J. Math. Phys. 17, 760 (1976)).*

*Work supported in part by the U.S. Air Force Office of Scientific Research

#Work supported in part by the National Research Council of Canada.

II. PUBLICATIONS (Cont'd)

15. L. MANDEL and E. WOLF: "Spectral Coherence and the Concept of Cross-Spectral Purity" (J. Opt. Soc. Am. 66, 529 (1976)).⁺
16. J.T. FOLEY and U. LANDMAN: "A Model Dielectric Function for Semiconductors: Si" (to be published in Phys. Rev. B).[†]
17. M.D. SRINIVAS: "Quantum Mechanics as a Generalized Stochastic Theory" (Submitted for publication in Phys. Rev. D).

⁺Work supported in part by the National Science Foundation.

[†]Work supported in part by the General Electric Foundation.

III. SUMMARIES OF PUBLICATIONS:

(For references see p. 3 of the present report).

1. Progress in Optics Volume XI 1973

MASTER EQUATION METHODS IN QUANTUM OPTICS

G. S. AGARWAL

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

This article presents a comprehensive review of master equation methods in quantum optics. After presenting an account of quantum mechanical phase-space methods, master equations are discussed for a general system, for systems interacting with stochastic perturbations and for open systems. Relaxation and Brownian motion of a quantum oscillator are considered. Superradiance and laser master equations are also discussed. Some related topics are reviewed and an application to solid state physics is given, as an illustration of the technique.

2. PHYSICAL REVIEW D VOLUME 8, NUMBER 4 15 AUGUST 1973

Radiating and Nonradiating Classical Current Distributions and the Fields They Generate*

A. J. Devaney[†] and E. Wolf

Department of Physics and Astronomy, University of Rochester, Rochester, New York, 14627

(Received 4 April 1973)

Several general theorems are established relating to well-behaved, localized, monochromatic current distributions and the fields that they generate. In particular, a necessary and sufficient condition for such a current distribution to be nonradiating is established and a general expression for all nonradiating current distributions of this class is obtained.

3. J. Math. Phys. Volume 15, Number 2 February 1974

Multipole expansions and plane wave representations of the electromagnetic field*

A. J. Devaney and E. Wolf

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

(Received 31 May 1973; revised manuscript received 2 August 1973)

A new and conceptually simple derivation is presented of the multipole expansion of an electromagnetic field that is generated by a localized, monochromatic charge-current distribution. The derivation is obtained with the help of a generalized plane wave representation (known also as the angular spectrum representation) of the field. This representation contains both ordinary plane waves, and plane waves that decay exponentially in amplitude as the wave is propagated. The analysis reveals an intimate relationship between the generalized plane wave representation and the multipole expansion of the field and leads to a number of new results. In particular, new expressions are obtained for the electric and magnetic multipole moments in terms of certain components of the spatial Fourier transform of the transverse part of the current distribution. It is shown further that the electromagnetic field at all points outside a sphere that contains the charge-current distribution is completely specified by the radiation pattern (i.e., by the field in the far zone). Explicit formulas are obtained for all the multipole moments in terms of the radiation pattern.

III. SUMMARIES: (Cont'd)

4. PHYSICAL REVIEW B

VOLUME 10, NUMBER 4

15 AUGUST 1974

Electromagnetic fields in spatially dispersive media*

G. S. Agarwal

Tata Institute of Fundamental Research, Bombay 5, India

D. N. Pattanayak and E. Wolf

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

(Received 17 January 1974)

The structure of the electromagnetic field in a spatially dispersive model medium occupying a plane parallel slab is obtained, free of several customary *ad hoc* assumptions made in other theories. The model medium is characterized by a dielectric response function appropriate to the neighborhood of an isolated-exciton transition frequency. The exact mode expansion for the electromagnetic field in the slab is derived and it is found that, unlike in the case of an unbounded medium, a single plane wave cannot be generated in the slab. An elementary solution (a single mode) is found to consist, in general, of six plane waves (four transverse and two longitudinal ones), coupled by two linear relations. These relations are shown to be equivalent to two nonlocal boundary conditions (of the form encountered in connection with the Ewald-Oseen extinction theorem in molecular optics), which the nonlocal contribution to the induced polarization must satisfy on the faces of the slab. This result resolves a long-standing controversy about the nature of the so-called additional boundary conditions that are generally believed to be required for solving problems of interaction of an electromagnetic field with a spatially dispersive medium. The results are applied to the problem of refraction and reflection on a spatially dispersive model medium occupying a half-space and a generalization of the classic formulas of Fresnel are obtained. The behavior of the reflected and transmitted waves as functions of the angle of incidence and of the frequency are illustrated by several figures. Our results are shown to differ from those obtained by Pekar in a well-known paper. The difference is traced to the nature of the additional boundary conditions postulated by Pekar; they are found to be inconsistent with the additional boundary conditions that we derive as an exact consequence of Maxwell's theory. Comparisons with several other theories, especially with those of Sein and Birman and of Maradudin and Mills are also made.

5. Optics Communications

Volume 12, Number 2

October 1974

ELECTROMAGNETIC SCATTERING FROM A SPATIALLY DISPERSIVE SPHERE[‡]

John T. FOLEY

Department of Physics and Astronomy, University of Rochester, Rochester, N.Y. 14627, USA

and

D.N. PATTANAYAK

Department of Physics, University of Toronto, Toronto, Ontario M5S 1A7, Canada

Received 1 August 1974

The problem of the scattering of a plane, monochromatic, linearly polarized, electromagnetic wave incident from vacuo onto a linear, homogeneous, non-magnetic, spatially dispersive sphere whose dielectric function is of the form

$$\epsilon_{ij}(\mathbf{k}, \omega) = \left[\epsilon_0 + \frac{\chi}{k^2 + \mu^2(\omega)} \right] \delta_{ij}$$

is solved within the framework of Maxwell's theory.

6.

PHYSICAL REVIEW B

VOLUME 11, NUMBER 4

15 FEBRUARY 1975

Structure of electromagnetic fields in spatially dispersive media of arbitrary geometry*

G. S. Agarwal

Tata Institute of Fundamental Research, Bombay 5, India

D. N. Pattanayak and E. Wolf

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

(Received 23 September 1974)

The nature of the electromagnetic field in a spatially dispersive medium, occupying an arbitrary domain V is investigated, under conditions when spatial dispersion effects arise from the presence of an isolated exciton transition band. It is shown that the electric field at frequency ω close to the exciton transition frequency may, in general, be expressed in the form $\vec{E}(\vec{r}, \omega) = \vec{E}_T^{(1)}(\vec{r}, \omega) + \vec{E}_T^{(2)}(\vec{r}, \omega) + \vec{E}_L(\vec{r}, \omega)$, where $\vec{E}_T^{(j)}(\vec{r}, \omega)$ ($j=1,2$) are transverse fields and $\vec{E}_L(\vec{r}, \omega)$ is a longitudinal field; and that each of these three fields satisfies a Helmholtz equation. The wave numbers occurring in the three Helmholtz equations are the roots of the dispersion relations appropriate to the medium. It is further shown that the three fields are coupled by a linear relation, which is shown to imply a recently derived nonlocal boundary condition on the nonlocal polarization, expressed in the form of an extinction theorem. These results are generalizations of certain results obtained not long ago by Sein, Birman and Sein, Agarwal, Pattanayak, and Wolf, and Maradudin and Mills.

7.

J. Math. Phys.

Volume 16, Number 8

August 1975

Foundations of a quantum probability theory*

M. D. Srinivas

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627
(Received 17 January 1975)

Statistical physical theories are frequently formulated in terms of probabilistic structures founded on a "logic of experimentally verifiable propositions." It is argued that to each experimentally verifiable proposition there corresponds an experimental procedure which, in general, alters the state of the system, and is completely characterized by a "measurement transformation" or "operation." An analysis of the relations among these experimental procedures leads us to a "logic of operations" which is quite different from the "lattice theoretic logics" that are often considered (albeit inadequate empirical justification), as models for the calculus of experimentally verifiable propositions of quantum theory. It is seen that the quantum probability theory based on the logic of operations provides the proper mathematical framework for discussing the statistics of successive observations in quantum theory. We also indicate how a theory of quantum stochastic processes can be formulated in a way similar to the Kolmogorov formulation of the classical theory.

8.

PHYSICAL REVIEW B

VOLUME 12, NUMBER 8

15 OCTOBER 1975

Electrodynamics of nonlocal media*

John T. Foley and A. J. Devaney

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627
(Received 26 March 1975)

A method, based upon Wiener-Hopf techniques, is presented for calculating the reflectivity of an s - or p -polarized plane electromagnetic wave from a semi-infinite medium whose dielectric response is spatially nonlocal. The method is applicable to media that can be adequately described by the dielectric approximation and by two scalar dielectric response functions, $\epsilon_1(\vec{r}, \omega)$ and $\epsilon_2(\vec{r}, \omega)$, which are subject only to weak boundedness and asymptotic conditions. As an example of the method, the reflectivities are calculated for a medium characterized by a dielectric response appropriate to the neighborhood of an isolated exciton transition frequency.

9.

PHYSICAL REVIEW D

VOLUME 13, NUMBER 2

15 JANUARY 1976

**Interaction of a moving charged particle with a spatially dispersive medium.
I. Structure of the electromagnetic field***

B. J. Hoenders^{*} and D. N. Pattanayak[†]

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

(Received 27 May 1975)

The general structure of the electromagnetic field is determined which is generated by a uniformly moving point charge interacting with a spatially dispersive medium forming a plane parallel slab. The direction of the point charge is taken to be at right angles to the faces of the slab, and the dielectric constant of the medium in the wave-vector frequency space is assumed to be of the form $\epsilon_{ij}(\vec{k}, \omega) = \delta_{ij}[\epsilon_0(\omega) + \chi/(\vec{k}^2 - \mu^2(\omega))]$. Expressions for Čerenkov and transition radiation fields associated with a uniformly moving point charge passing from a vacuum into such a medium, forming a half space, are also obtained.

10.

PHYSICAL REVIEW D

VOLUME 13, NUMBER 2

15 JANUARY 1976

**Interaction of a moving charged particle with a spatially dispersive medium.
II. Čerenkov and transition radiation***

B. J. Hoenders^{*} and D. N. Pattanayak[†]

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

(Received 27 May 1975)

In the preceding paper, we obtained expressions for the electromagnetic field generated by the interaction of a uniformly moving electron with a spatially dispersive half-space. One part of the field was identified with Čerenkov radiation and the other part with transition radiation. In this paper it is shown that the integrals involved in the Čerenkov part can be evaluated in closed form in terms of elementary functions, and we obtain three distinct threshold conditions for Čerenkov radiation instead of the usual one, as is the case in a spatially nondispersive medium. Furthermore, we obtain for each frequency component the asymptotic expansion of the transition radiation part of the field, valid at points that are far enough away from the path of the electron and from the boundary.

11.

PHYSICAL REVIEW D

VOLUME 13, NUMBER 4

15 FEBRUARY 1976

**Scattering states and bound states as solutions of the Schrödinger equation
with nonlocal boundary conditions***

D. N. Pattanayak

Department of Physics, University of Toronto, Toronto M5S 1A7 Canada

E. Wolf[‡]

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

(Received 21 July 1975)

The problem of determining the Schrödinger wave function of a nonrelativistic particle that is either scattered by a potential of a finite range or that is bound to it is reformulated in a novel way. It is shown that in either case the wave function must satisfy a certain boundary condition on the surface that delimits the effective range of the potential. For scattering states the boundary condition is analogous to the mathematical formulation of the Ewald-Oseen extinction theorem of classical electromagnetic theory. The new formulation is illustrated by determining the scattering states and the bound states for a central potential. It is also shown that a boundary condition that is used in band-structure calculations in solids is an immediate consequence of our quantum-mechanical extinction theorem for bound states.

12.

PHYSICAL REVIEW D

VOLUME 13, NUMBER 4

15 FEBRUARY 1976

New theory of radiative energy transfer in free electromagnetic fields*E. Wolf[†]*Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627*

(Received 21 August 1975)

A new theory of radiative energy transfer in free, statistically stationary electromagnetic fields is presented. It provides a model for energy transport that is rigorous within the framework of the stochastic theory of the classical field as well as within the framework of the theory of the quantized field. Unlike the usual phenomenological model of radiative energy transfer that centers around a single scalar quantity (the specific intensity of radiation), our theory brings into evidence the need for characterizing the energy transport by means of two (related) quantities: a scalar and a vector that may be identified, in a well-defined sense, with "angular components" of the average electromagnetic energy density and of the average Poynting vector, respectively. Both of them are defined in terms of invariants of certain new electromagnetic correlation tensors. In the special case when the field is statistically homogeneous our model reduces to the usual one and our angular component of the average electromagnetic energy density, when multiplied by the vacuum speed of light, then acquires all the properties of the specific intensity of radiation. When the field is not statistically homogeneous our model reduces in good approximation to the usual phenomenological one, provided that the angular correlations between plane wave modes of the field extend over a sufficiently small solid angle of directions about the direction of propagation of each mode. It is tentatively suggested that, when suitably normalized, our angular component of the average electromagnetic energy density may be interpreted as a quasiprobability (general quantum-mechanical phase-space distribution function, such as Wigner's) for the position and the momentum of a photon.

13.

PHYSICAL REVIEW D

VOLUME 13, NUMBER 8

15 APRIL 1976

Resonance states as solutions of the Schrödinger equation with a nonlocal boundary condition*

D. N. Pattanayak

Department of Physics, University of Toronto, Toronto M5S 1A7 Canada

E. Wolf

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

(Received 17 November 1975)

Resonance states of a system consisting of a particle interacting with a finite-range potential are introduced in a novel way, independent of the notion of scattering. It is shown that a resonance wave function satisfies a certain nonlocal boundary condition on the surface that delimits the range of the potential. With a central potential our general boundary condition reduces to a set of local ones that are identical with those obtained previously by Humblet and Rosenfeld by different methods.

III. SUMMARIES: (Cont'd)

14. J. Math. Phys.

Volume 17, Number 5

May 1976

Asymptotic approximations to angular-spectrum representations*George C. Sherman, Jakob J. Stamnes,[†] and Éamon Lalor[†]*The Institute of Optics, The University of Rochester, Rochester, New York 14627*
(Received 29 April 1975)

Under rather general conditions, a time-harmonic wave field $u(x, y, z)$ can be represented in a half-space $z > 0$ by a double integral known as the angular spectrum of plane waves. The representation divides naturally into the sum of two double integrals, one of which (u_H) is a superposition of homogeneous plane waves and the other (u_I) is a superposition of inhomogeneous plane waves. We obtain asymptotic approximations to $u(x, y, z)$, u_H , and u_I valid when the point of observation of the field recedes towards infinity in a fixed direction through a fixed point. The results apply when the spectral amplitude of the plane waves belongs to a specific class which arises frequently in applications. Our approach is based on the method of stationary phase, which we extend in order to permit the presence of inhomogeneous waves in the integrand. Although the analysis of u requires that we distinguish the directions that are perpendicular to the z axis from the directions pointing into the half-space $z > 0$, the results for the former case are the same as would be obtained by taking the appropriate limit in the results of the latter case. We obtain the general form of the asymptotic sequence appropriate for expanding u and present explicit expressions for the first two terms. Our derivation justifies the results of previous heuristic treatments. The analysis of u_H and u_I requires separate treatments for directions that are (i) perpendicular to the z axis, (ii) parallel to the z axis, and (iii) neither perpendicular nor parallel to the z axis. In contrast to the behavior of u , the asymptotic behavior of u_H (and of u_I) differs in the different cases. In each case, we obtain the general form of the appropriate asymptotic sequence and present the first term explicitly.

15. J. Opt. Soc. Am.

Volume 66, Number 6

June 1976

Spectral coherence and the concept of cross-spectral purity*

L. Mandel and E. Wolf

Department of Physics and Astronomy, The University of Rochester, Rochester, New York 14627
(Received 26 January 1976)

A new measure of correlations in optical fields, introduced in recent investigations on radiometry with partially coherent sources, is studied and applied to the analysis of interference experiments. This measure, which we call the complex degree of spectral coherence, or the spectral correlation coefficient, characterizes the correlations that exist between the spectral components at a given frequency in the light oscillations at two points in a stationary optical field. A relation between this degree of correlation and the usual degree of coherence is obtained and the role that the complex degree of spectral coherence plays in the spectral structure of a two-beam interference pattern is examined. It is also shown that the complex degree of spectral coherence provides a clear insight into the physical significance of cross-spectral purity. When the optical field at two points is cross-spectrally pure, the absolute value of the complex degree of spectral coherence at these points is found to be the same for every frequency component of the light. This fact is reflected in the visibility of the spectral components of the interference fringes formed by light from these points.

III. SUMMARIES: (Cont'd)

16. Phys. Rev. B. (To be published)

A MODEL DIELECTRIC FUNCTION FOR SEMICONDUCTORS: Si

J.T. Foley and U. Landman

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

A model dielectric function for semiconductors based on the two band tight-binding model of Chadi and White is presented. The complex dielectric function includes transitions in the entire frequency range and satisfies the Kramers-Kronig relations and the f-sum rule. A method of analyzing optical experiments is discussed and applied to Si.

17. Phys. Rev. D. (Submitted for publication)

QUANTUM MECHANICS AS A GENERALIZED STOCHASTIC THEORY IN PHASE SPACE

M. D. Srinivas

Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627

In this paper we formulate a new stochastic description of quantum mechanics in phase space. The theory of phase space representations of quantum mechanics, initiated by Wigner, Groenewold and Moyal and systematized recently by Agarwal and Wolf is essentially a single-time theory, in that it deals only with the quantum mechanical joint distribution functions for position and momentum at single instant of time. We develop a natural multi-time extension of such a single-time theory.

We consider a class of multi-time phase space distribution functions such that an arbitrary quantum multi-time correlation function can be expressed as a phase space average of the form encountered in classical stochastic theories. We study the non-classical features of these multi-time distribution functions and show that they may be considered as characterizing a generalized stochastic process in phase space. We demonstrate that the multi-time distribution functions that correspond to Hamiltonian evolution of isolated quantum systems, satisfy a certain condition that may be regarded as characterizing a generalized Markov process. We also investigate certain special features of the generalized stochastic processes that characterize the evolution of open systems.

IV. ADVANCED DEGREES EARNED BY GRADUATE RESEARCH ASSISTANTS WHILE
EMPLOYED ON THIS PROJECT

S. M. -TEHRANI, M.S. degree, University of Rochester (1976).

Title of Thesis: "Angular Correlation Tensors of Free Stationary
Electromagnetic Fields".

V. LIST OF PERSONNEL

The following persons assisted in the research under this grant:

- E. WOLF, Professor of Physics, Principal Investigator
- A. J. DEVANEY, Research Associate
- D. N. PATTANAYAK, Research Associate
- B. J. HOENDERS, Visiting Research Associate
- J. T. FOLEY, Research Assistant
- M. SRINIVAS, Research Assistant (Research Associate 1/6/76 - 2/29/76)
- S. M. -TEHRANI, Research Assistant
- M. S. ZUBAIRY, Research Assistant

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18. SUPPLEMENTARY NOTES The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Radiation, multipole expansions, spatial dispersion, Cerenkov and transition radiation, scattering, resonance, radiative transfer, spectral coherence.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents summaries of investigations carried out under the above grant, chiefly in the following areas: radiation from classical charge-current distributions, multipole expansions, electrodynamics in spatially dispersive media, Cerenkov and transition radiation, quantum scattering and resonance theory, radiative energy transfer in free electromagnetic fields, spectral coherence.		