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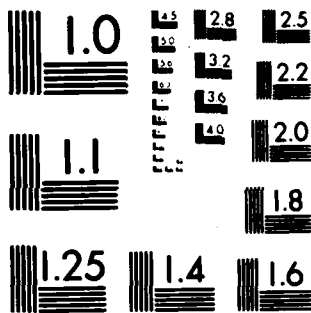
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Date: July 3, 1983

Title: Final Report

Contractor: Cornell University

Principal Investigator: Richard L. Liboff

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <b>A discussion of work performed under contract AFOSR 78-3574 during the '78-'83 support interval is presented. A list of technical reports issued during this period is included together with a description of ongoing research.</b>		

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This document presents abstracts of

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## I. Technical Reports

Titles and abstracts of key technical reports issued under contract AFOSR-78-3574 are listed below:

### Report APS 79

"First-Order Estimate of the  
Saha Equation for a Helium Plasma"

July 21, 1980

#### Abstract

Closed forms for the ratios  $n_e n_i / n_o(q)$  and  $n_e^2 n_\alpha^2 / n_o(q)$  are obtained for a high temperature helium plasma; they include approximate expressions for electrostatic interaction. The analysis further assumes that ground state contributions dominate partition function summations. In the above expressions,  $n_e$  is the electron number density,  $n_i$  is the ion number density,  $n_\alpha$  is the alpha particle number density, and  $n_o(q)$  is the number density of helium atoms excited to the  $q$ -quantum number state. These ratios are found to be maximum at the quantum state  $q = \sqrt{R/k_B T}$ , where  $R$  is the Rydberg constant,  $k_B$  is Boltzmann's constant and  $T$  is the temperature.

### Report R-1-80

"Exact Solutions for Interacting  
Finite Potential Wells"

October 25, 1980

#### Abstract

Exact wavefunctions and eigenenergy relations are obtained for a bi-well potential as a function of inter-well displacement and single-well parameters. The proliferation of energies is

shown explicitly as the wells are brought into close proximity. The model is compared with the opaque-division-wall model. These results find important application in laser and nuclear physics.

Report JPP-1-81

"Dual Propagation and Absorption  
in a Warm Plasma Half Space"

March 2, 1981

Abstract

The relativistic Vlasov equation together with Maxwell's equations are used in a study of p-polarized electromagnetic waves incident on a warm plasma half-space. The domain for dual propagation of longitudinal and transverse waves is derived as a function of density, temperature and incident angle at a given frequency. Expressions for the reflection and absorption coefficients are obtained in the non-relativistic limit. It is found that maximum absorption occurs at an angle dependent on the density and temperature of the plasma, above which dual propagation will not occur. It is inferred that the density-temperature space available for dual propagation diminishes with the growth of the maximum angle for such propagation.

Report AJP-2-81

"Electrostatics in the Plane"

March 10, 1981

Abstract

Electrostatic laws are obtained for charges constrained to lie in a plane. The corresponding electric field  $E$  in the plane

obeys neither Poisson's equation nor Gauss' law. A vector field  $\underline{\Lambda}$  is constructed which does satisfy these equations and which is a functional of the charge density. Various limiting forms of the coupling dyad  $\underline{\bar{M}}$  are obtained where  $\underline{E} = \underline{\bar{M}} \underline{\Lambda}$ .

Report R-2-81

"Electron Density Profile  
in a Recombining Plasma"

September 1, 1981

Abstract

A rate equation for electron density in a recombining plasma dominated by collisional ionization and three-body recombination is presented. The ionization coefficient is derived from a kinetic prescription and its inverse recombination coefficient is obtained employing the principle of detailed balance. Assuming a quasi-temporal equilibrium in the plasma, an expression is obtained for the space dependence of the electron density which is given by,

$$N_e(y) = N_e(0) \left[ \frac{1}{1 + \frac{\bar{K}y}{1 - \alpha y}} \right]$$

where  $\bar{K}$  and  $\alpha$  are constants and  $y$  is nondimensional displacement. Results are found to be in rough agreement with experimental observation.

Report JQRST-1-82

"Review of Fundamental  
Processes for Matter-Radiation  
Interaction II"

January 28, 1982

Abstract

A concise review is presented of fundamental quantum electrodynamic processes which are relevant to X-ray lasers, grasers, and superpowerful lasers. Transition rates and cross sections are derived for atomic and free-electron Thomson scattering, Kramers-Heisenberg, and Raman scattering in the dipole approximation; Rayleigh scattering and Cerenkov effect. The report includes a table of reaction rates, cross sections, stopping power, and power spectra for all processes considered.

Report ZN-2-82

"Properties of a One-Dimensional  
Coulomb Gas"

May 11, 1982

Abstract

The BBKGY equations for  $N$  identical, impenetrable, charged particles which move in one dimension and lie in a charge neutralizing background, are shown to separate into  $N$  uncoupled equations for the sequence of  $N$  reduced distributions. The potential relevant to any subgroup of  $s$  adjoining particles is that of an  $s$ -dimensional harmonic oscillator whose frequency is the plasma frequency of the aggregate. The  $s$ -particle spatial equilibrium distribution reveals that particle vibrations remain centered

about fixed, uniformly distributed sites as  $\rho/T$  goes from zero to infinity, where  $\rho$  is particle density and  $T$  is temperature. Thus it is concluded that the system suffers no change in phase for all  $\rho$  and  $T$ .

Report JPP-3-82

"Kinetic Theory for a Short-Wavelength  
Lasing Plasma"

September 1, 1982

Abstract

A kinetic analysis is made of a reacting plasma dominated by three-body recombination and ionization, together with collisional and radiative excitation and de-excitation of atomic states. The plasma includes excited atoms, ions, electrons and photons. The kinetic theory yields rate equations for these species, together with explicit expressions for relevant rate coefficients. In the limit of spatial homogeneity and assuming atom and electron densities are close to equilibrium, an explicit form is obtained for the radiation absorption coefficient per unit length. A criterion is then constructed for population inversion. Application to a helium-like active medium (e.g.  $\text{Al}^{+11}$ ) and hydrogen-like passive medium (e.g.  $\text{Al}^{+12}$ ), at electron temperature of 300 eV, reveals that population inversion ensues at electron densities in excess of  $10^{20} \text{ cm}^{-3}$ . Algebraic solution of atomic state rate equations demonstrates that the absorption coefficient grows insensitive to photon-atom interactions with increasing electron density.

Report R-4-82"Exciton-Laser Amplifier"

December 1, 1982

Abstract

A laser-amplifying device is described which is based on the stimulated decay of excitons in a pure crystal. An estimate is made of the gain of the device. At a typical frequency the gain is found to be appreciably large thus suggesting practical application of the laser amplifier.

Report LJTP-1-83"Induced Decay of Positronium  
and Grasers"

April 22, 1983

Abstract

The differential cross section and the total cross section for the stimulated decay of positronium by an incident photon of frequency  $\omega$  is calculated as a function of the dimensionless variable  $\xi = \hbar\omega/mc^2$ . For  $\xi \gg 1$  the total cross section is found to decrease as  $\xi^{-2}$ . We also look at the particular case of positronium in a black-body radiation field. Expressions for the number of induced annihilations per second as functions of the dimensionless ratio  $mc^2/kT$  and the number of positronium atoms are obtained. It is found that this rate is proportional to  $(kT/mc^2)^2$  for  $kT \ll mc^2$  and to  $(kT/mc^2)\ln(kT/mc^2)$  for  $kT \gg mc^2$ .

The possibility of utilizing induced two-photon decay of positronium as a  $\gamma$ -ray laser at the wavelength  $\gamma_c/2$  is examined, where  $\gamma_c$  is the Compton wavelength.

Report R-3-83

"Study of a Nuclear  $\gamma$ -Ray Laser"

June 3, 1983

Abstract

Two radioactive nuclear decay schemes are examined as possible  $\gamma$ -ray lasing devices. These involve certain relatively long-lived first excited states above the ground state and higher lying isomeric states. The population of such excited states, neglecting stimulated decay, is found to vary as  $(\tau_s/\tau_\ell)N_\ell(0)[1 - \exp(-t/\tau_s)]$  where  $\tau_s$  is the decay time of the  $s$ th excited state of the lasing nucleus and  $\tau_\ell$  is the decay time of the parent species whose initial concentration is  $N_\ell(0)$ . For decay to the stable nuclei  ${}^{66}\text{Dy}^{161}$  and  ${}^{77}\text{Ir}^{191}$ , the decay ratio  $\tau_s/\tau_\ell$  is found to be infinitesimally small. A brief discussion of the emitted multipole fields is included.

Report R-4-83

"Unified Theory of Plasma Correlations"

June 13, 1983

Abstract

A unified approach to the theory of correlations in a plasma is presented, based on the BBKGY hierarchy. The theory is applied to a one-component plasma with the Coulomb interaction modified

to include effects of the background. Closed integro-differential equations in space and time are obtained for the two-particle correlation function in both the strong and weak coupling limits. In the weak-coupling domain,  $\gamma \ll 1$ , the time-independent analysis returns the well-known linearized Debye-Huckel result, where  $\gamma$  is the plasma parameter. In the strong-coupling domain with  $\gamma \gg 1$ , the resulting two-particle 'total' correlation function exhibits decaying oscillatory behavior for particle separation of the order of the effective interparticle range.

## II. Ongoing Research

Continuing research is directed at the following areas:

### 1. Kinetic Theory of Strongly Coupled Plasmas.

In recombination lasing the plasma parameter,  $\gamma \geq 1$ , and the plasma is said to be strongly coupled. Kinetic properties of such plasmas permit the evaluation of parameters important to the design and implementation of short wavelength lasing.

(See Report No. R-4-83.)

### 2. Recombination Coefficient

Recombination and ionization coefficients are also relevant to recombination lasing. Except for J. J. Thomson's classical result for recombination, formulations of this coefficient rest on gross assumptions concerning properties of a plasma. Ongoing research in this area seeks to construct the recombination coefficient from first principles. This result would be particularly relevant to non-equilibrium plasmas.

### 3. Lasing Criterion

Research in this area seeks to obtain an explicit analytic expression for the integral criterion found by Heffernan and Liboff (Report No. JPP-3-82) for population inversion in a dense recombining plasma. Such an analytic form would permit graphical display which, in turn, would prove valuable to experimental research. Further study will generalize the Heffernan-Liboff criterion to include dynamics of the ion component of the plasma. Due to the complexity of this problem, influence of ion dynamics in the first formulation was minimal.

### III. Conclusions

Research performed during this support interval has been particularly valuable to the theory and development of short-wavelength lasing. The criterion developed in Report JPP-3-82 for population inversion in recombination lasing will prove important to future experiments in this area.

A new theory for strongly coupled plasmas was developed during this interval which has far-reaching consequence in the study of dense recombining plasmas (Report No. R-4-83). This phase of plasma occurs for sufficiently high electron density and sufficiently low electron temperature. The relatively high  $Z$ -number which occurs in typical recombining plasma experiments also contributes to strong coupling. This theory will prove valuable in construction of transport as well as thermodynamic properties of plasmas in the strong-coupling temperature-density domain.

Two new schemes were introduced which may possibly give rise to short-wavelength lasing. These schemes are effected through:

- (a) induced decay of Positronium (Report No. IJTP-1-83),
- (b) induced decay of excitons in pure crystals (Report No. R-4-82).

In addition to these two schemes, an analysis was also presented for lasing through induced decay of long-lived nuclear isomeric states (Report No. R-3-83).

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