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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A thermal energy beam source of rare gas metastable atoms (He,Ne,Ar) has been designed and constructed. These low energy high flux beams have been used to excite ions of the Group II metal atoms in Penning ionizing collisions. We find that optical emission from the excited ions is linearly polarized along the beam axis. This non-statistical population of the m_J states of the excited ion is a sensitive measure of the interaction between the reactants of the Penning collision process. (cont'd)

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We have also examined kinetic processes related to volume recombination of electrons and ions in the afterglow of a laser initiated discharge in a mixture of potassium atoms in a high pressure buffer of Krypton. Time dependent optical emission from excited states populated in the afterglow of an ionizing laser pulse is utilized to determine electron temperatures and densities. The electron energy loss rate can then be determined.

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Technical Report

The purpose of the research program is to investigate collisional processes which are important in determining energy balance in discharge plasmas and their afterglows. Two of these processes which are currently under investigation in our laboratory are Penning ionization and volume recombination processes involving ions and electrons.

Penning Ionization

Models for Penning ionization processes provide a semi-empirical basis for the calculation of total cross sections. Such refinements as spin and coherence transfer and the energy and angular distributions of the emitted electrons are, in general, outside the scope of the present theoretical models. The work on the selection rules on Δm_ℓ in Penning collisions is intended to establish the validity of a molecular-orbital correlation model proposed by Micha and Nakamura[(1)] to explain the observed angular distribution of Penning electrons[(2)].

Several high flux beam sources have been designed and constructed. The first is a source of helium neutral atoms with kinetic energies of several kilovolts[(3)]. A large polarization has been observed for the emission lines of strontium and calcium excited by a beam of neutral helium atoms with 800 eV lab energy. The measured value of 15% indicates a preferential population of the magnetic substates of the correlated atom states of the target species. Depolarization of the emission in a magnetic field has been observed demonstrating the feasibility of Hanle-type lifetime measurements[(4)].

On the basis of our observations, we conclude that at 800 eV collision energy the molecular state $B^1\Sigma$ correlating with the separated atom states $He(^1S_0)$ and $Sr(^1P_1)$ is preferentially populated. Thus, states of M_1=0 in the $Sr(^1P_1)$ level are preferentially populated giving rise to the observed polarization.

A second high flux beam source has been constructed for the production of helium, neon, and argon metastable atoms[(5)]. The source is a pulsed or dc electric discharge in an expanding gas nozzle. A metastable flux of 3.5×10^{14}, 1.5×10^{14}, and 7.2×10^{13} atoms/s sr has been achieved with most probable energies of 66, 72, and 74 meV for the helium, neon, and argon sources, respectively. Time of flight measurements showed the widths of the respective velocity distributions to be 45%, 27%, and 27%. The beam composition was determined with the use of particle multipliers and by the observation of the optical excitation produced in certain target gases.

The low energy beams of unpolarized metastable atoms have been used to create Sr ions in their lowest $^2P_{3/2}$ state. The ratios of the cross-sections for the formation of this state of Sr^+ by helium, neon, and argon are 1:0.4:1.4, respectively. In the case of the helium and argon metastable beams the emission from this $^2P_{3/2}$ state of Sr^+ is of sufficient intensity that its polarization can be readily observed. Relative to the beam axis the emission is linearly polarized with values of +2% and +1% for excitation by the helium metastable and argon metastable beams, respectively. The observation of the alignment of ions formed in Penning ionization reactions provides another probe of the nature of these reactions. This probe is a particularly sensitive measure of the interaction between the excited ion and the ground state rare gas atom which are formed in the reaction. In addition, these reactions can provide a source of excited, aligned ions upon which other experiments may be performed.

Volume Recombination at High Densities

A new technique has been applied to the study of volume recombination processes in alkali vapors and alkali-rare gas mixtures. Resonant two photon ionization of the alkali atom creates a well-defined line source of charge in the vapor cell. The time dependent decay of electron density or optical emission from excited states of the alkali atom are monitored in the afterglow of the fast laser pulse.

Electron-ion recombination and other collisional processes for systems of alkali vapor in the presence of high pressure ($\sim$1 atm) noble gas have been of interest in connection with alkali exciplex laser and rocket exhaust plume studies. Electron-ion recombination studies to date have been mainly concerned with hydrogen, noble gases or atmospheric gases constituents, except for the experiments on Cs[(6)]. Most experiments employ an electrical discharge at low pressure to produce the ionization. We have studied electron excitation and electron-ion recombination of K ions in a laser initiated plasma in the presence of Kr of density [Kr] = 2.4×10^{19} cm^{-3}. Such laser initiated plasma has the advantage of high plasma density ([e]$\sim 10^{14}$cm^{-3}), a well defined geometry for the plasma region and, importantly, a short ($\sim$4nsec) impulse source so that fast decay rates can be measured and diffusion can be neglected.

In this work, 4 nsec, 120 μJ laser pulses from a dye laser pumped by a N_2 laser and tuned to the 404 nm($4^2S_{1/2}$ - $5^2P_{3/2}$) line of K were focused into a beam of waist $\sim$1 mm wide inside an alkali-resistant glass (Corning #1720) cell containing distilled K with Kr of density [Kr] = 2.4×10^{19} cm^{-3} in an oven. Ionization of K was produced by resonance excitation to the $5^2P_{3/2}$ state followed by photoionization: $K(5^2P_{3/2}) + h\nu \rightarrow K^+ + e$. Superelastic atom-electron collisions and electron impact ionization may also contribute as in McIlrath et al[(7)] and Tam et al[(8)]'s experiments, but the simple stepwise optical excitation and ionization scheme described above is adequate to account for most of the ionization. Fluorescence from the plasma region was detected by a S-20 photomultiplier through a scanning monochromator and the amplified signal was viewed with an oscilloscope or fed to a PAE 160 box-car integrator for averaging and temporal dispersion.

Results obtained to date are shown in figures 1 and 2. Figure 1 is a plot of the density of excited K atoms as a function of ionization potential for a number of times into the afterglow. The slope and intercept yield the electron density and temperature which is then plotted in Fig. 2 as a function of time after the ionizing laser pulse.

The measured electron loss rate due to recombination agrees reasonably well with a simplified collisional-radiative model which includes energy loss due to radiation and elastic collisions with the buffer gas. A detailed report is to appear in Chemical Physics Letters.[9]

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1. "Non-Statictical Excitation of the Magnetic Substates of the $^1P_1$ Level of Group II Metal Atoms in Collision with 800 eV Helium Atoms". D. W. Fahey and L. D. Schearer, Phys. Lett. 65A, 215 (1978).

2. "High Flux Beam Source of Fast Neutral Helium Atoms". D. W. Fahey, L. D. Schearer, and W. F. Parks, Rev. Sci. Instrum. 49, 503 (1978).

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5. "Laser Initiated Afterglow in a High Pressure K-Kr Mixture". L. K. Lam and L. D. Schearer, to be published, Chem. Phys. Lett.

6. "High Flux Beam Source of Thermal Rare-Gas Metastable Atoms". D. W. Fahey, W. F. Parks, and L. D. Schearer, submitted to Rev. Sci. Instrum.

Presentations Dec. 1977-1978

1. "A Xenon-Ion Laser Pumped Dye Laser for the Tuning Range 400-500 nm". D. W. Fahey and L. D. Schearer, Washington APS meeting April 1978.

2. "Non-Statistical Excitation of the Magnetic Substates of the $^1P_1$ Level of Group II Metal Atoms in Collision With 800 eV Helium Atoms". D. W. Fahey, W. F. Parks, and L. D. Schearer, Washington APS meeting April 1978.

3. "Laser Initiated Afterglow in a High Pressure K-Kr Mixture". L. K. Lam and L. D. Schearer. 31st Annual GEC meeting, Buffalo, Oct. 1978.

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5. "Penning Ionization" - an invited seminar at JILA Boulder, Colo. Dec. 1977. L. Schearer.

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Figure captions

1. Population distributions of excited potassium atoms vs. excited state energy for various delay times in the afterglow. Data points for different delay times have been offset vertically with multiplicative factors as indicated to avoid overlap. Circles are nS-4P data and crosses are mD-4P data. The slope yields the electron temperature, Te.

2. Plot of electron temperature, T_e and electron density, N_e as a function of time in the afterglow.

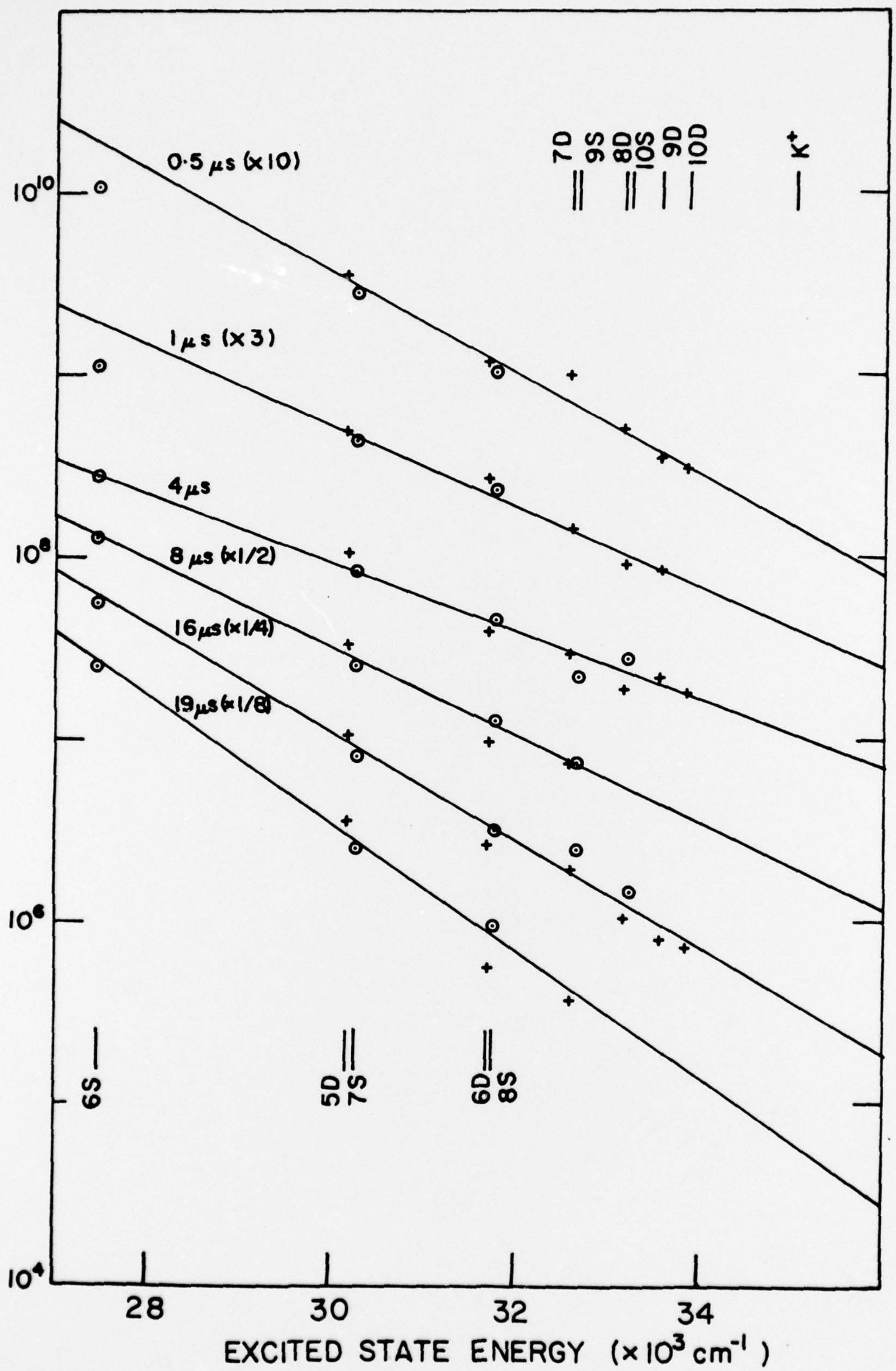
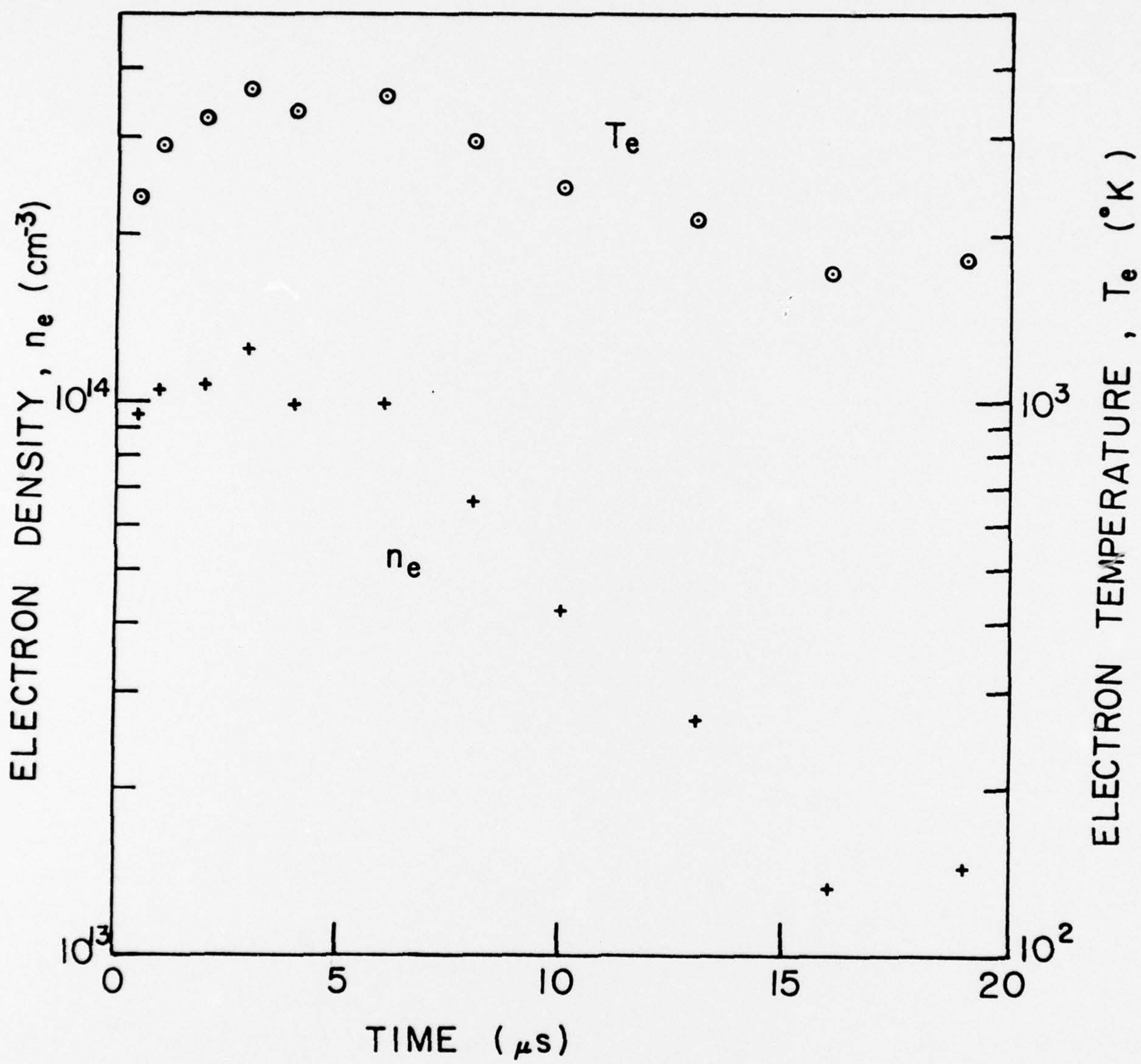

0·5 μs (x10)
1 μs (x3)
4 μs
8 μs (x1/2)
16 μs (x1/4)
19 μs (x1/8)
7D
9S
8D
10S
9D
10D
K⁺
6S
5D
7S
6D
8S
10¹⁰
10⁸
10⁶
10⁴
28
30
32
34
N*/2J+1 (cm⁻³)
EXCITED STATE ENERGY (x10³ cm⁻¹)

Fig. 1



ELECTRON DENSITY, n_e (cm^{-3})
ELECTRON TEMPERATURE, T_e (°K)
TIME (μs)
T_e
n_e
10^{14}
10^{13}
10^{3}
10^{2}
0
5
10
15
20

Fig. 2