EXPERIMENTAL STUDIES OF ELECTRON IMPACT DEPOPULATION
OF EXCITED STATES OF ATOMS: APPLICATION TO
LASER DEVELOPMENT FOR FUSION AND
ISOTOPE SEPARATION

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I. INTRODUCTION

Rare gas and rare gas halide excimers are attractive candidates for use in efficient high power lasers because in general the ground state has a repulsive character or at worst only a very shallow well. Thus, once stimulated emission from the attractive excited state has occurred, the excimer dissociates, thereby precluding saturation effects due to radiation trapping.

Population of the excited state excimer may proceed along several different kinetic paths, with one path employing excitation of the rare gas atom to a metastable state.¹ Since the metastability of the state precludes optical excitation via E1 transitions, other excitation procedures must be used. The most efficient of these procedures is generally recognized to be e-beam or e-beam-controlled-discharge pumping.²

The very presence of the electrons which induce the optically forbidden excitation also results in a possible depopulation of the metastable rare gas state via superelastic, inelastic, and ionizing collisions. While the loss of population due to superelastic collisions is undesirable, it is not nearly so severe a problem as a process which results in the ultimate ionization of the rare gas atom, since an ionizing process produces an additional electron which can affect the stability of the entire pumping process. Ionization need not proceed directly from the metastable state but can result from a multistep process involving intermediate states which are excited in inelastic electron collisions. Indeed, it is well known³ that the cross sections for electron impact excitation of the $ns\ ^3P_{0,2}$

heavy rare gas metastable states to the next higher lying n-p manifold are as large as $\sim 10^{-14} \text{ cm}^2$. Stepwise ionization can then be a significant depopulation mechanism.

It is the general goal of this research program to investigate the depopulation of metastable states of rare gas atoms by electron impact. Superelastic, inelastic, and ionization processes will be studied using a crossed electron-atom beams configuration. The incident atomic beam will be prepared with approximately 40% of the atoms in the metastable state. This state preparation will be accomplished by first producing an ion beam in a duoplasmatron ion source⁴ and then allowing the ions to undergo resonant charge transfer with the appropriate alkali analog atom.⁵

In order to investigate multiple step ionization processes it is necessary to populate more highly excited states before studying the electron impact phenomena. Since the excitation energy from the rare gas ground state to the excited states of interest is $\geq 10 \text{ eV}$, it is necessary to start with the atoms prepared in the metastable state if optical excitation is to be used. A triple crossed beams configuration with the electron beam along one axis, the metastable rare gas beam along a second axis, and optical radiation from a tunable dye laser along a third axis will then be used to study electron scattering from the short lived higher lying states. If the laser is tuned to the $1s_5-2p_9$ transition, where the Paschen notation $1s_5$ corresponds to the 3P_2 metastable state, then a high population of the $2p_9$ state will be maintained since the only El

(optically) allowed decay is to the $1s_5$ metastable state. Measurement of the absorbed laser light combined with the known radiative lifetime of the $2p_9$ state then determines the absolute population of the $2p_9$ state.

An electron spectrometer with ≤ 50 meV resolution will be used to study the electron scattering cross sections for the superelastic, inelastic and ionization channels with the rare gas atoms in the metastable and more highly excited states. A schematic diagram of the experimental layout is shown in Fig. 1.

II. SCIENTIFIC PROGRESS

During the first nine months of this project, the major components of the experiment have been designed and significant construction has taken place. In the following paragraphs we will summarize the status of the various elements of the experiment.

Duoplasmatron Ion Source

A duoplasmatron ion source,⁴ employing an accel-decel extraction system, has been designed and fabricated. The source, shown in Fig. 2, is based upon the Los Alamos Triton configuration⁶ and is expected to produce rare gas ion beams with currents in excess of 1 mA at an energy of ~1 keV.

Stainless steel construction has been employed with metal gasket seals in order to minimize the presence of contaminants which can lead to discharge instabilities and inefficient ion production. Additional precautions have been taken to further reduce contaminants: surfaces of electrodes which might be expected to be heated significantly by electron bombardment have been machined from refractory materials and have been provided with freon refrigeration. Freon refrigeration is also used to cool the solenoidal magnet. In order to permit empirical optimization of the ion current, the source has been designed with electrodes that can be aligned under operation.

All power supplies necessary for operation have been either obtained from commercial suppliers or fabricated in house.

Testing of the source is expected to commence shortly.

Alkali Charge Exchange Cell

An alkali charge exchange cell using a recirculating heat pipe principle⁷ has been designed and is currently being fabricated. The cell, shown in Fig. 3, consists of a reservoir containing several ampoules of alkali metal and a charge-exchange canal. The ampoules can be cracked sequentially while the system is under vacuum, thereby minimizing unnecessary consumption and maximizing cleanliness. The reservoir and canal are heated with Thermocoax to achieve the necessary metal vapor density in the charge exchange region. The ends of the canal are water cooled to condense the vapor at the ends and thus prevent excessive loss of the alkali from the cell. A wire mesh wick on the inner walls of the canal provides the necessary capillary action to return the condensed vapor to the reservoir in liquid form.

The charge exchange cell is housed in a stainless steel vacuum vessel which is pumped by an oil diffusion pump stack incorporating a freon baffle, liquid nitrogen trap and pneumatically actuated stainless steel gate valve. The effective pumping speed of the stack is rated at 1200 l/sec and should maintain a pressure of $\leq 10^{-5}$ Torr in the charge-exchange cell vacuum vessel. The duoplasmatron, which need operate at only about ~1 Torr, will be pumped through the charge-exchange cell vacuum vessel.

Based upon measurements of Neynabler and Magnuson⁵ and those of Pradel et al.⁸ it is expected that for an alkali target thickness of $\sim 10^{14}$ atoms/cm² at least 30% of the rare gas ion beam will be converted to rare gas metastable neutrals. With a 1 mA ion beam, a metastable beam intensity of $\sim 2 \times 10^{15}$ atoms/sec is expected. Since the ion beam

velocity is $\sim 5 \times 10^6$ cm/sec for heavy rare gases with an energy of 1 keV, a metastable atom density of $\geq 10^9$ cm $^{-3}$ can be expected at the crossed beams interaction region where the metastable atom beam diameter will be ~ 0.5 cm.

Construction of the charge-exchange cell and vacuum containment vessel is still in progress but should be completed shortly. The pump stack has been purchased so that the entire metastable beam system will be available for testing upon completion of the charge exchange cell.

Electron Scattering Region

Design studies of a spherical electron monochromator-spectrometer have been undertaken. However, no construction has been started thus far. Should the metastable atom beam be operational before the monochromator/spectrometer fabrication is complete, arrangements have been made to borrow a spectrometer from the University of Massachusetts.⁹

The electron optical components will be mounted on a flange which is compatible with the scattering chamber of an existing electron-atom crossed beams apparatus. The existing scattering chamber is capable of achieving a pressure of $\sim 5 \times 10^{-10}$ Torr, with adjacent chambers maintained at a pressure of $\sim 5 \times 10^{-8}$ Torr. A single stage of differential pumping between the charge exchange chamber and the scattering chamber therefore should be sufficient to allow the scattering chamber to be maintained at $\sim 10^{-9}$ Torr.

This residual pressure corresponds to a density of $3 \times 10^7 \text{ cm}^{-3}$ in the background gas, or a factor of 30 below the target beam density. These same target and background densities were used recently in a successful crossed e-H beams experiment,¹⁰ where cross sections were as low as $\sim 5 \times 10^{-17} \text{ cm}^2$ for some measurements.

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Fig. 1. Schematic diagram of triple crossed-beams configuration.

Fig. 2. Scale drawing of duoplasmatron ion source at left and charge exchange cell at right.

Fig. 3. Diffusion pump stack and charge exchange cell.