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COHERENT X-RAYS BY STIMULATED EMISSION OF RADIATION.(U)

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Substantial progress has been made towards the realization of a short-wavelength charge-exchange laser which is driven by pulsed capacitor discharge. Parallel experimental and theoretical efforts have led to the point that observation of laser action is believed to be imminent. The basic resonant charge-exchange reaction studied is $He^+ + Cs \rightarrow He^* + Cs^+$.

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COHERENT X-RAYS BY STIMULATED EMISSION OF RADIATION

Final Report

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During the course of this contract substantial progress has been made towards the realization of a short-wavelength charge-exchange laser which is driven by pulsed capacitor discharge. Parallel experimental and theoretical efforts in this laboratory have led us to the point where we believe that observation of laser action is within our grasp in the near future.

The basic resonant charge-exchange reaction we have studied is

$$He^{+} + Cs \rightarrow He^{*} + Cs^{+} \quad ; \qquad (1)$$

with the excited He^{*} decaying by emission of a 584 Å photon to the neutral ground state. In the geometry we have chosen, a dense helium plasma moving at 10^{6} cm/sec collides with an essentially stationary gas of neutral cesium atoms. Along the collision interface a population of the He 2p state is created through charge-exchange collisions. With sufficient initial densities of helium ions and cesium atoms, enough collisions will occur in times short compared to the spontaneous lifetime that the upper level is pumped into inversion and laser action will result.

I. Theory.

The process has been studied both theoretically and experimentally. The theoretical program has dealt with the rather complex collision dynamics of plasma and gas cloud. A set of rate equations has been developed which describe the collision process, both the primary process of the charge exchange and a number of possible competing processes. Attention has been paid to: 1) electron impact ionization of the cesium, which competes with the basic reaction in the plasma-gas collision; 2) electron impact de-excitation of the excited helium; 3) photoionization of the cesium atoms by light from the plasma; and 4) atom-atom and atom-ion momentum transfer collisions, which set an upper limit on the penetration depth of the charge exchange region into the cesium target. We have determined that processes 2) and 3) can be neglected, but processes 1) and 4) must be included in any analysis of the collision dynamics.

A set of rate equations has been solved analytically for idealized boundary conditions, and on a computer for boundary conditions consistent with the experimental density distributions of plasma and gas pulses. The results of this analysis give density "windows" on cesium atom and helium ion concentrations, within which observable inversion should take place. These densities are $\sim 10^{16}$ cm^{-3} for the helium ions and 10^{17} - 10^{18} cm^{-3} for the cesium atoms.

II. Experiment.

1. Plasma Generation and Characterization.

A parallel rail-type Marshal gun plasma source has been constructed and studied in some detail. The gas load to this plasma gun is supplied by a fast valve system of our own design which injects a relatively fast-rising dense pulse of gas into the region between the parallel rails of the plasma gun. Once the desired density of gas is present between the rails, an arc is lit and accelerated down the rails by a triggered capacitive discharge. This process generates a relatively hot ($\sim$ 5 eV) dense ($\sim 10^{15}$ cm^{-3}) helium plasma which is virtually completely ionized. This plasma is in the form of a well localized transient pulse having a velocity of roughly $2 \cdot 10^{6}$ cm/s and a rise time of less than 1 μs. Our present system displays 10-20% reproducibility. Both dual electric probe studies and spectroscopic studies have been used in order to characterize this plasma source.

2. Pulsed High-Density Metal Vapor Source.

In order to produce a high-density cesium vapor target with a sharp rise time, we invented a novel source of high-density atomic metal vapors. This source consists of a fast, high-energy xenon flash tube placed behind a transparent substrate. Onto the front of this substrate we evaporate a thin coating of cesium metal. When the flash tube is fired, an intense light pulse of approximately 20 μs duration heats and flash evaporates a strip of the cesium coating approximately 2 mm × 70 mm. The dense cloud of cesium vapor produced in this manner at the face of the slide serves as the target for our beam clashing experiment. By employing standard atomic beam techniques using a surface ionization hot-wire detector, we have found that this is a thermal source of atomic cesium producing densities in excess of 10^{16} cm^{-3} close to the face of the slide. The atomic cesium vapor is delivered in the form of a pulse propagating at about $5 \cdot 10^4$ cm/s and having a width at the slide of roughly 10 μs. The density of this pulse drops off as $1/r^2$ as the pulse travels away from the slide, and is consistent with a collisionless infinite line source with radial spreading due to a Maxwell-Boltzmann velocity distribution at a temperature on the order of 10^3 °K.

3. Beam Clashing Experiments.

By firing the helium plasma from our plasma gun at the cesium-vapor target produced by the flash evaporation source mentioned above, we have performed beam clashing experiments which yield results that are consistent with charge exchange pumping of the type shown in Eq. (1). Thus far, we have not observed laser action, and believe that we are operating below threshold. Our time-resolved studies of the beam clashing, however, do indicate a 50-fold enhancement of the spontaneous emission at 584 Å. This demonstrates that resonant charge exchange is, indeed, taking place in the interaction region and resulting in an increase in the population of the upper level of the transition. As further evidence that this is a resonant charge-exchange effect, we observe no enhancement of the spontaneous emission signal when the cesium vapor is photoionized by an intense light pulse just prior to the arrival of the plasma. These results, coupled with the theoretical predictions, seem to indicate that greater cesium densities and higher collision velocities will result in even greater upper level populations and eventually an inversion which will result in laser action.

III. Summary.

As a result of our coordinated theoretical and experimental efforts we feel that we have made great progress towards the construction of the first short wavelength charge exchange laser system. We have constructed and characterized the basic components of the system, and we have a sound theoretical model which indicates what direction our research must take in order to achieve laser action at 584 Å. We have been very encouraged by our beam clashing results wo far, and we feel that in the near future we will demonstrate a charge-exchange pumped X-ray laser.

Publications Produced or Reporting Work Done
Under This Grant

D. K. Anderson, J. McCullen, Marlan O. Scully and John F. Seely, "Analysis of Short-Wavelength Charge-Exchange Lasers Via Plasma-Gas Beam Clashing," Optics Commun. 17, 226 (1976).

D. K. Anderson, D. Jones, and J. D. McCullen, "Pulsed High-Density Source of Cesium Atoms," Rev. Sci. Instruments. (To be published.)

J. D. McCullen (General Title of Lectures: "X-Ray Lasers") Lectures presented at Nato Advanced Study Institute on Coherence in Spectroscopy and Modern Physics, Villa le Pianore, Versilia, Italy, July 17 - 30, 1977. Proceedings to be published.

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