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FINAL REPORT

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Overview

During this subcontract, we have developed and demonstrated the basic tools needed for selective detection of krypton isotopes in the Photon Burst Mass Spectrometry technique. We have assisted Los Alamos in implementing these techniques on the mass separator at Los Alamos, and have participated in initial tests of the instrument. In the following paragraphs we describe in more detail progress made on the four general tasks covered by the subcontract. In all four cases the progress made has already been communicated to LANL personnel in greater detail than summarized here at the time the results were achieved, and has been included in quarterly progress reports and presentations to DOE.

Photon burst measurements on Mg^+ demonstrating high isotopic selectivity

We have set up a simplified photon burst mass spectrometer with the purpose of investigating and demonstrating the fundamental principles of the method. Our instrument, shown in Fig. 1, includes a Colutron ion source for producing Mg^+ ions, a Wien filter mass spectrometer to separate isotopes of Mg if desired, bending optics to bring the ion beam into the same path as the laser beam, a chamber with two photon burst detectors, a Brewster entrance window for the laser beam, a doubled dye laser to produce 280nm light, and the vacuum pumps and electronics required to operate this system.

Considerable effort went into the design of the ion optics to transport the ion beam. Four different complete designs were constructed and tested. Simplified schematics of these designs are shown in Fig. 2. In the final design (Fig. 1) the ion beam is transported at 1-5 keV and then decelerated to 200-500 eV just before the photon burst detection region.

With this apparatus we were able to demonstrate a selectivity of 5×10^7 for discriminating a rare Mg isotope (e.g., $^{27}Mg^+$) against the stable Mg isotopes ($^{24,25,26}Mg^+$). The results are shown in Fig. 3. Only one background burst in more than 2 hours was recorded for frequencies ≥ 3 GHz off resonance. As can be seen in Fig. 3, the $^{27}Mg^+$ peak has a separation of nearly

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6 GHz from the neighboring $^{26}\text{Mg}^+$ peak. A paper has been submitted for publication. [1]

We have also developed a two theoretical models to predict photon burst signals in our apparatus and to evaluate future apparatus designs, including the LANL PBMS instrument. In Fig. 4 it is seen that our experimental results (the dots) confirm very well the theoretical predictions (the solid line) for both the single detector and dual detector setups.

Charge exchange of Kr^+ with Cs and Rb to produce metastable Kr atoms

We have designed and constructed, in cooperation with LANL personnel, a new type of recirculating alkali vapor cell. It is shown in Fig. 5. Cs or Rb atoms are evaporated in the bottom chamber, rise upward as an atomic beam, condense to a liquid on the top, and flow down the sides by gravity. Operation with both Cs and Rb for extended periods of time (several months) with 25 gram charges has been demonstrated. A second similar cell has been constructed for the LANL PBMS instrument.

We have demonstrated charge transfer in collisions of Kr^+ with Cs or Rb with an efficiency of $>95\%$. We have shown that the angular distribution of the charge exchange beam is approximately the same as the incident ion beam. We are preparing for experiments on the measurement of the populations of the Kr metastable states resulting from the charge exchange process, using the Mg^+ photon burst apparatus described above.

Development of a diode laser system for photon burst detection of Kr^+

We have modified a commercial current- and temperature-stabilized diode laser by the addition of an external grating for feedback. (Fig. 6) With this laser we have shown that the frequency can be tuned in the neighborhood of 811 nm. We have taken a spectrum of the fluorescence from the various isotopes of Kr in the $1s_5$ metastable state following charge exchange. An initial spectrum shown in Fig. 7. Peaks with widths of $<2.7\text{eV}$ have been seen. We also investigated locking of the diode laser to a spectral line in a uranium hollow cathode lamp by its optogalvanic signal. Marginal success was obtained because the signal was quite weak on the 811 nm line.

Measurements of photon bursts detection of Kr

It was decided in the course of this project that the primary effort to first detect photon bursts from Kr would be best carried out on the LANL PBMS instrument. We have assisted on the design, construction and testing of this instrument, and have transferred our knowledge of the technology we have developed to our collaborators at LANL. Due to delays in the

construction of the photon burst chamber at LANL, photon bursts were not seen until late in this project.

As a support for this work, we carried out experiments at CSU to characterize the quantum efficiency, angular and spatial response, and cooling of the R4519 photomultiplier tubes for Kr photon burst detection. We also have developed and tested designs for the electronics to sort out and identify photon bursts involving multiple detectors. A two detector design was used in the Mg^+ experiments.

Presentations

In addition to conducting these experiments, CSU personnel participated in most of the presentations of the project to DOE.

Problems encountered, recommended solutions

No significant problems were encountered. The locking of the laser to an optogalvanic signal was only marginally successful. We suggest that for now locking of the laser is not necessary as the width of the Kr^* peaks at 500-2000 eV will still be quite broad. Should improvement be made in reducing the energy spread of the LANL ion source to <1 eV, locking to a fixed reference interferometer or some other spectral line, or the use of a much larger uranium hollow cathode lamp, as once existed at LANL, are recommended.

Summary

This project was overall very successful. Information and technology were transferred promptly to LANL, and contributions to the development of the LANL instrument were substantial.

- [1] R. D. LaBelle, C. S. Hansen, M. M. Mankowski and W. M. Fairbank, Jr., "Isotopically Selective Atom Counting Using Photon Burst Detection", submitted to Phys. Rev. Letters.

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Fig. 1. Photon Burst Mass Spectroscopy apparatus at CSU used for measurement of 5×10^7 isotopic selectivity in Mg^+ .

Fig. 2. Evolution of the design of the ion optics for the Photon Burst Mass Spectroscopy apparatus at CSU.

Fig. 3 Isotopic abundance sensitivity measured as a function of detuning from the $^{26}\text{Mg}^+$ resonance. The calculated burst transition frequency of the next heavier isotope, $^{27}\text{Mg}^+$, is marked by the arrow at 5.9 GHz, for 500 eV beam energy.

Fig. 4. Comparison of experimental and theoretical burst and coincidence rates for (a) one detector and (b) two detectors. Good agreement is seen.

Fig. 5. The new design for a recirculating alkali vapor charge exchange cell.

Fig. 6. Design of external cavity diode laser at CSU; upper view: optical diagram, lower view: physical structure.

Fig. 7. Spectrum of Kr isotopes at 763 eV taken with the CSU charge exchange cell and 811nm diode laser and a single photon burst collector.