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In a first measuring period, experiment PS207 was set up and run using the 105 MeV/c beam of LEAR. For the first time, antiprotonic X-rays were observed with a crystal spectrometer.

The main results are:

- 90% of the incoming antiporotons were stopped in the center of the cyclotron trap at 30 mbar gas pressure.
- Several hundreds of Lα X-rays both from antiprotonic hydrogen and deuterium have been observed with the Bragg crystal spectrometer.
- With the spherically bent quartz and silicon crystals having a diameter of 10 cm, resolutions consistent with the limits as obtained from crystal diffraction theory have been achieved.
- The size of the X-ray source, i.e., the diameter of the stop volume, has been measured with the crystal spectrometer to be ≤20 mm (FWHM).
- The broadening of the Lα transitions in hydrogen and deuterium due to the multiplet structure of the 2p levels is clearly seen when compared to the calibration lines from antiprotonic helium and neon. (The analysis of the data is still in progress).
- A CCD detector installed close to the stop volume in the bore hole of the magnet was able to operate up to a rate of $2\text{-}3 \cdot 10^5$ incoming antiprotons per second.

In conclusion, it was shown that the performance of the present setup is able to achieve the goals of proposal PS207. A high statisctics measurement of antiprotonic hydrogen is foreseen in November and December 1995. However, to fullfil our proposal in its entirety, 2 to 3 years are necessary.

Further progress can be achieved using more advanced techniques for diffraction crystals and CCD detectors:

- The resolution of the crystal spectrometer can be improved by a factor of 1.5 and 2 in the case of antiprotonic hydrogen and deuterium, respectively, when using asymmetric cut Bragg crystals. (For asymmetric cut crystals, the reflecting planes have a finite angle with the surface of the mirror.) In the case of the Lα transition in hydrogen, a decrease of the rocking curve width from 140 meV to 86 meV is predicted. For deuterium, a decrease of the width from 290 meV to 140 meV is possible which is a factor of 2-3 less than the predicted total energy splitting of the 2p hyperfine transitions. The counting rates are expected to be 50% - 80% as compared to the now used symmetric Bragg case.
- In a test experiment performed in collaboration with ILL (Grenoble) and the Friedrich-Schiller-University at Jena, for the first time the reduction of the reflection width could be established for spherically bent asymmetric cut crystals (at an energy of 5.4 keV). Further investigations will then extend the lower energies needed at LEAR. It is planned to have a complete set of asymmetric cut crystals ready in about one year from now.
- A new type of CCD (fully depleted pn-CCD) is being set up as a dedicated high-rate detector. Such a device can be read out faster by a factor of 100 than the CCD presently used in the bore hole of the cyclotron trap. This allows a further increase of the incoming antiproton rate by at least a factor of three. Furthermore, due to a tenfold larger depletion depth of 300 μm the detection efficiency is close to 90% even at energies beyond 10 keV. With such a detector, the observation of the Kα transition in antiprotonic deuterium should be feasible.

The PS207 collaboration plans to ask for beam time beyond 1995 to apply the new techniques. A better crystal resolution improves considerably the significance of the data and the use of a high-rate CCD allow the observation of weak lines beyond the present detection limit.

To summarize, the use of a crystal spectrometer improves the energy resolution by three orders of magnitude, which opens a new era in antiprotonic atom spectroscopy. The gain in resolution opens a new insight in the formation and deexcitation of antiprotonic atoms and dedicated experiments investigating antiproton capture or few electron systems attached to an antiproton-nucleus core will become feasible. Several possible experiments using the Bragg spectrometer have been discussed in LE$\overline{p}$ working groups.

For the PS207 collaboration

D. Gotta

appendix A1: Annual report of the Institut für Kernphysik, KFA Jülich, 1994 on the LEAR activity (the figures are taken from the online data analysis and show only a minor part of the data collected)

appendix A2: contribution to the LEAP conference 1992, Courmayeur, Italy

X-rays from Light Antiprotonic Atoms Measured with The Low-Energy Bragg Spectrometer

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The aim of LEAR experiment PS207 is the high resolution spectroscopy of Lyman and Balmer transitions of the antiprotonic hydrogen and helium isotopes to determine hadronic shifts and broadenings of the low-lying atomic hyperfine states [1]. In the present experiment, for the first time, antiprotonic X-rays have been measured using a crystal spectrometer.

The 105 MeV/c antiproton beam of LEAR was injected into the cyclotron trap and stopped to about 90% in hydrogen, deuterium, helium, and neon gas for 30 mbar hydrogen and pressures of equivalent stopping power. With the present beam intensities, about 10^9 antiprotons could be stopped per hour. As Bragg crystals spherically bent quartz and Si crystals of 100 mm diameter and a radius of curvature of about 3 m have been used [2]. The reflected X-rays were detected in a charge-coupled device (CCD) with a pixel size of 22.5 μm x 22.5 μm, which provides an excellent position resolution. In addition, the good energy resolution (about 180 eV at 1.7 keV) allow an efficient background rejection.

The width of the X-ray source provided by the stop volume in the center of the cyclotron trap was found to be ≤ 20 mm (FWHM) in diameter from a preliminary analysis. The measurement was done with the Lα X-rays from antiprotonic hydrogen and the 5→4 transition of antiprotonic helium.

Fig. 1 shows the Lα transitions of antiprotonic hydrogen and deuterium as obtained from the online analysis, where a cut is applied to the energy spectrum around the transition energy of 1.738 and 2.317 keV, respectively. An overall detection efficiency for one Lα X-ray from hydrogen or deuterium of about $1\text{-}2\cdot10^{-8}$ per incoming antiproton was achieved for the whole setup. The absolute yield of the antiprotonic Lα transition is about 50% both for hydrogen and deuterium.

The natural widths of the antiprotonic transitions are orders of magnitude smaller than the natural widths of fluorescence X-rays excited by means of X-ray tubes. Usually, fluorescence X-rays are the only possibility to investigate the performance of Bragg crystals. In the case of silicon and sulphur, the natural line widths of the Kα transitions are

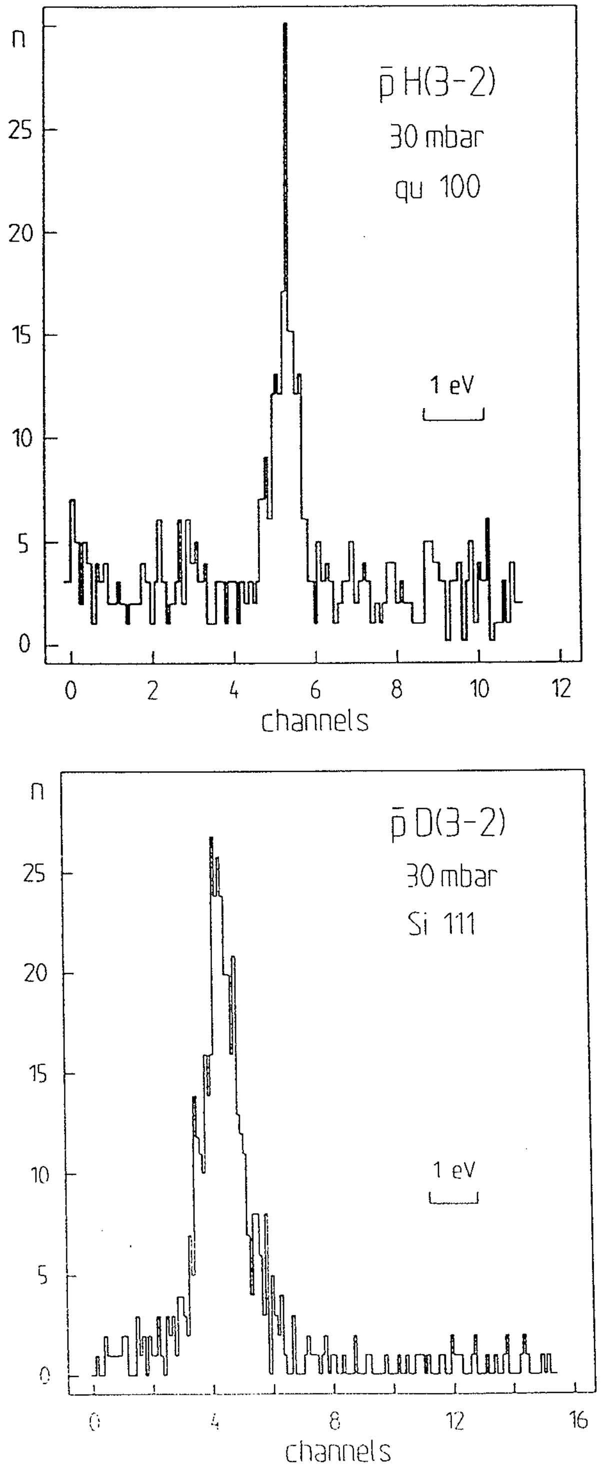
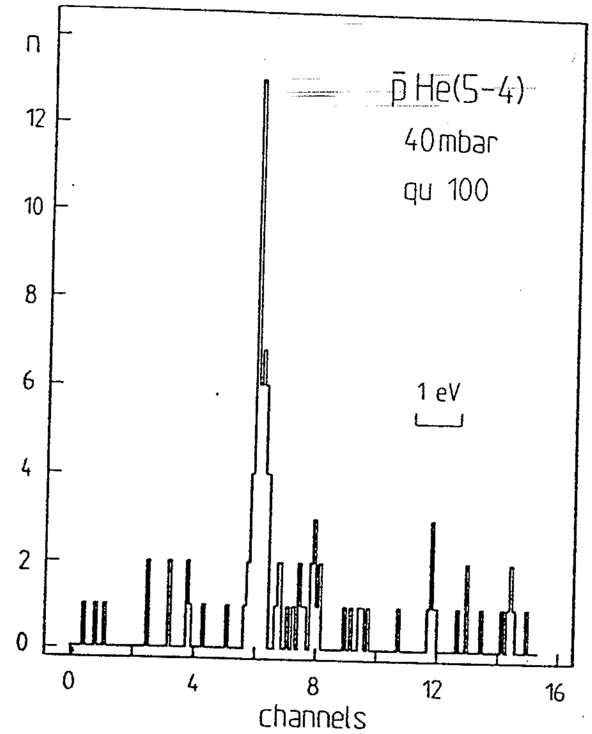


Fig.1 Position spectra of the CCD showing the Lα transitions of antiprotonic hydrogen [E=1.7368 keV] and deuterium [E=2.3165 keV]. The X-rays were reflected in first order by a sperically bent quartz or silicon crystal.



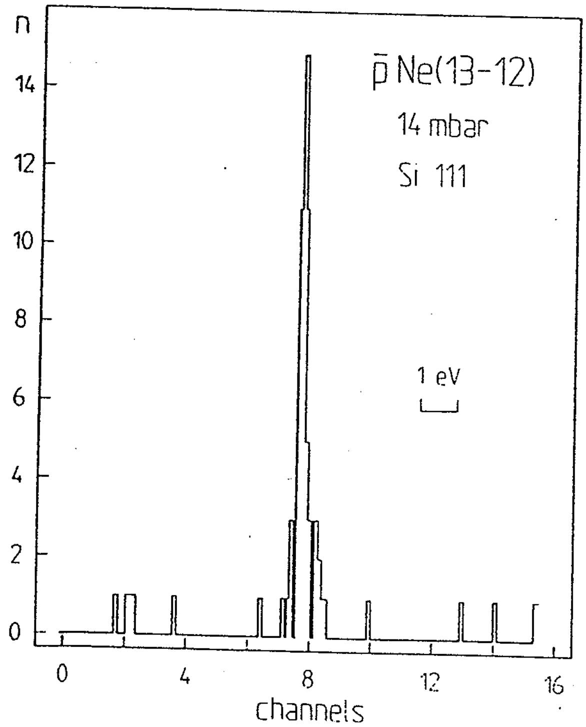


Fig.2 Position spectra of the CCD for the transitions 5→4 of antiprotonic ^{4}He [E=1.7986 keV] and 13→12 of antiprotonic ^{20}Ne [E=2.4441 keV]. These narrow transitions are used to determine the response functions of the apparatus for the measurements for the hydrogen isotopes.

0.52 and 0.77 eV and thus exceeding the width of the rocking curves by a factor of about 4 [3].

Ideally, the response function of the Bragg spectrometer is obtained from antiprotonic X-rays from atomic states not affected by strong interaction, finite size effects, or electron screening. The natural width of such X-ray transitions is due to a pure electric dipole transition and, therefore, only of the order of a few meV. Any broadening of the reflection width then only contains contributions of the rocking curve, the geometrical aberration, and the position resolution of the detector.

The response functions at Bragg angles close the setup for antiprotonic hydrogen and deuterium Lα have been measured with the transitions 5g→4f from antiprotonic ^{4}He at 1.797 keV and 13→12 from antiprotonic ^{20}Ne at 2.444 keV at equivalent pressures corresponding to 30 mbar hydrogen (fig. 2). In the case of antiprotonic ^{4}He, it was possible to observe also the parallel transition 5f→4d. The yields of such parallel transitions provide new experimental information on a region of the atomic cascade which was accessible up to now only indirectly from cascade calculations.

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