ANTIDEUTERONS AT LEAR

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PHYSICS MOTIVATION

Antideuteronic atoms

In contrast to other negative elementary particles being captured in orbits of exotic atoms (μ−, π−, K−, Λ−, Ω−), the antideuteron has spin 1 and is a weakly bound composite. The spin 1 leads to a more complex line structure than usual; the weak binding gives rise to qualitatively new features (break up) as discussed later. For lighter nuclei (Z < 30) the antideuteron is captured in high-n orbits and cascades down to energy levels with small angular momenta, where it annihilates via strong interaction with the nucleus. Energy measurements in the intermediate part of the X-ray cascade yield information about the mass, the magnetic moment, the quadrupole moment, and the electric polarizability of the antideuteron. Energy shifts and level widths in the atomic orbits near the nucleus are related to the low-energy D-nucleus strong interaction. Measurements of the residual fragments will show if a single p or n or both particles will annihilate on the nucleus. For heavier nuclei an interesting new phenomenon might occur1,2. In the intermediate part of the cascade, the electric field as seen by the orbiting antideuteron becomes strong enough to dissociate the antideuteron into n


and $\bar{p}$. Thus a Coulomb dissociation of a bound $\bar{D}$ would be observable for the first time. It may well be that the antiproton stays with the nucleus and cascades down to more deeply bound levels, so that X-ray lines of antideuteronic and antiprotonic atoms appear in the same spectrum. Before the break-up, strong polarizability effects lead to sizeable energy shifts in the levels ($10^{-3}$ effects), which could give valuable information about the quark structure within the antideuteron.

**Antideuteron-Nucleus Interaction**

It is suspected that the implantation of antiprotons might give rise to the formation of hot quark matter$^3$. Replacing antiprotons by antideuterons would result in more pronounced effects.

**Production of Antinuclei**

Antideuterons are highly desirable as an intermediate step for the production of heavier antinuclei. However, the ideas seem to be very speculative at present and will not be pursued further.

**PRODUCTION OF ANTIDEUTERONS**

**High-Energy Antideuterons**

Antideuterons at higher energies were observed on several occasions$^4$, for example at Serpukhov, where at 13 GeV/c seven antideuterons per burst were found, emerging from a long, small-acceptance beam$^5$. Under the present AA conditions, it would be expected that about two antideuterons per burst would be stored in the AA ring at 3.5 GeV/c$^6$. At 7 GeV/c this number would be increased by a factor of 40. Another factor of 80 can be gained in the production rate if antideuteron beams of 30 GeV/c would be produced from 200 GeV primary protons. Thus there is no lack of high-energy antideuterons; however, their storage and deceleration to lower energies, as discussed here, needs an enormous effort.

**Low-Energy Antideuterons**

A very efficient way to produce antideuterons at low energies is to start with a system with baryon number equal to $-2$. The process $\bar{n}$ (thermal) + $\bar{p}$ (rest) + $\bar{D}$ + $\gamma$ would be ideal but seems out of reach for the moment. More realistic is the idea of using the process$^7$

$$\bar{p} + \bar{p} + \bar{D} + \pi^-.$$

This is well known from the analogous reaction $p + p + D + \pi^+$ which has been intensively studied in the past. The maximum cross-section (3.2 mb) occurs at 500-600 MeV/c c.m. momentum. The process happens
the in 8% (!) of all \( \bar{p}p \) reactions. Two schemes have been proposed for using this reaction for low-energy \( \bar{D} \)-production:

i) Colliding \( \bar{p}p \) beams

Two rings of LEAR dimensions with one interaction region are needed. In both rings, \( 3 \times 10^{11} \bar{p} \)'s of 500 MeV/c are stored which circulate in opposite directions. Fast cooling systems are needed in order to compensate for beam blow-up effects. With the present LEAR performance, no high luminosities can be achieved, but even with this design 25 \( \bar{D} \) per second would be produced along the interaction region. These antideuterons would have a kinetic energy of 14 MeV (ideally suited for stop experiments) and would be produced into the full solid angle, with a preference towards the directions of the colliding beams. The pions have an energy of 130 MeV and can be used as a tag for antideuterons. With two dedicated rings of higher luminosity than the present LEAR design, \( \bar{D} \) rates of one or two orders of magnitude higher would not seem to be excluded.

ii) Storage of antideuterons

Two rings of different dimensions are filled with antiprotons of different momenta, e.g. 1.5 GeV/c and 0.33 GeV/c. The interactions of the parallel beams occur in an intersection region. A part of the antideuterons produced has the same momentum as the antiprotons of higher energy (1.5 GeV/c) and can thus be stored in the larger ring. This mechanism works for special combinations of the two momenta. All antideuterons which cannot be stored because of the finite acceptance of the outer ring can be used for experiments as in scheme (i). Here, however, they are confined in a finite solid angle, their energies depending on the angles. The merit of the scheme is that it makes very efficient use of the antiprotons: about 0.5 \( \bar{D} \)'s for 1000 interacting antiprotons can be stored even in a small momentum acceptance of only 1%. After storage and deceleration the cooled antideuteron beams can be used for experiments on internal or external targets.

CONCLUSIONS

An efficient way to obtain a large number of \( \bar{D} \) per second is to produce them at high momenta with a high-energy accelerator. Storage and deceleration, however, would need a tremendous effort. The schemes working with two low-energy \( \bar{p} \) rings seem to be more realistic. Even under the present luminosity restrictions, first experiments with antideuterons could be started. The intensity of antideuteron beams would immediately profit from improved beam-handling techniques and could reach values comparable to present conventional beams, even with excellent beam emittances.