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RECENT PROGRESS IN THE POLARIZATION OF VERY SHORT-LIVED NUCLIDES

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ABSTRACT

In order to study electromagnetically mass-separated short-lived isotopes by the technique of nuclear orientation, a facility has been set up with two complementary polarization mechanisms. The first is based on cryogenic polarized target techniques, whereas the second is designed for the production of polarized beams.

1. Introduction

The interest of nuclear physicists in short lived nuclides being ever increasing, it is clear that every available method for studying decaying isotopes is to be applied and adapted for on-line use. Of special importance are measurements of spins, moments and multipolarity mixing ratios, all quantities that are obtainable from polarized nuclei. It is our aim to develop an apparatus which is suitable for a very large range of nuclear lifetimes and for all masses. In order to cover as many nuclides as possible, the system is designed to incorporate two main polarizing mechanisms, complementing each other. The first is based on the realisation of H/T-values higher than 10^3 T/K, implying low temperatures and high magnetic fields. Clearly, however, this method must be limited to lifetimes > spin lattice relaxation times of the specific impurity-host combination. Therefore the second mechanism leads to an "in beam" polarization, by producing a polarized beam of short living nuclides without any delay. In this case the limitation is set by the time the polarization can be maintained.

Both mechanisms ask for challenging technical solutions. In the first case we need a ^{3}He-^{4}He-dilution refrigerator with a direct (i.e. without any window) beam access for on-line separation compatibility. The second case requires a beam transmitting UHV chamber and specific ion optics needs.

2. The refrigerator

The refrigerator apparatus is totally based on a standard commercial ^{3}He-^{4}He-dilution system, with a 300 μW cooling power at 100 mK. But special features are included in the design of the cryostat, as a consequence of the need to implant 50 keV ion beams in a sample at ~15 mK. It was built with a large diameter top loading facility (19 mm), and equipped with a "side access", i.e. a direct beam access from room temperature to the sample holder, without any radiation shield. The sample dimensions were chosen large enough to guarantee an efficient beam transport.

Obviously this design put some technical difficulties, mainly with respect to the limitation of the heat input to the sample holder, and the cooling procedure itself. To overcome the former problem we designed a

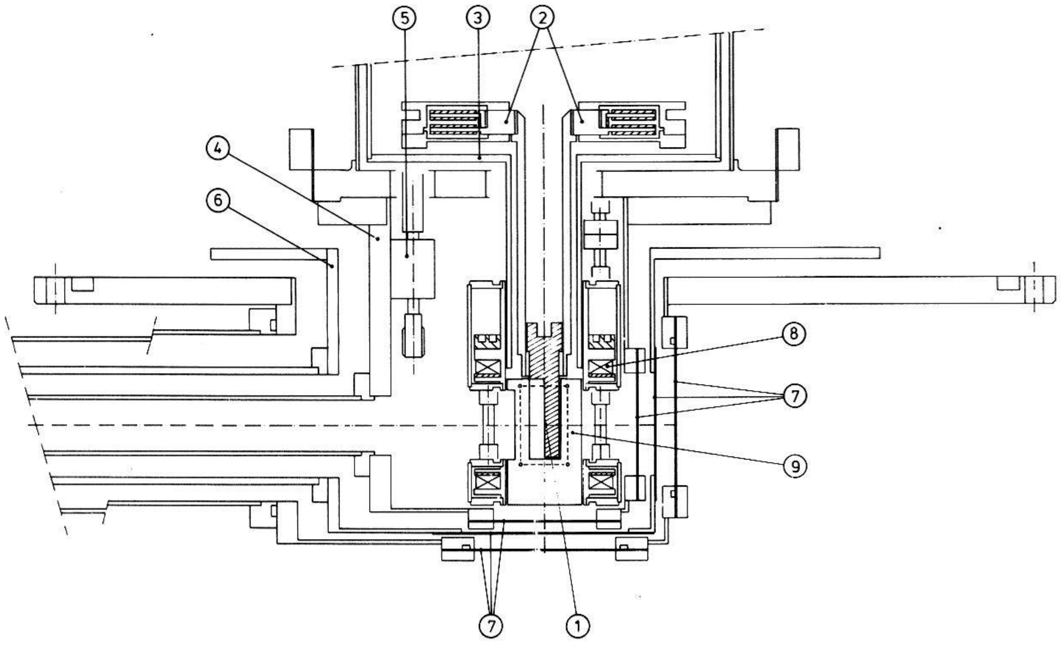

Fig. 1 Cross section of the bottom of the cryostat with attached side access. 1) sample holder; 2) mixing chamber of dilution unit; 3) 0.6 K shield; 4) 4.2 K shield; 5) side access baffle driver; 6) 77 K shield; 7) thin windows; 8) 0.5 T split coil magnet; 9) RF coil.

4K cooled extension of the inner cryostat vacuum, properly coated with black absorbing paint and with a length of 1m, to reduce the room temperature solid angle by a factor 10^4. This tube is terminated by a movable diaphragm at 77 K, and surrounded by a concentric liquid nitrogen cooled tube. All cooling is obtained from thermal contact with the main cryostat shields, and the temperature transitions are built from thin walled stainless steel bellows. To obtain the base temperature the side access can be closed off by a movable baffle at 4 K. After several tests it was shown that gravitational instabilities of the exchange gas in such a horizontal extension do not appear during the cooling procedure.

The present lay-out of the bottom of the cryostat and the attached side access is shown in fig. 1, including the superconducting split pair magnet and the NMR-coil surrounding the sample. The performance of the side access system is presented in fig. 2. Clearly these results are given without beam load – the purity of the separated beams depends on the adopted ion source. In any case special care should be taken to establish a very good thermal contact between the sample and the mixing chamber of the

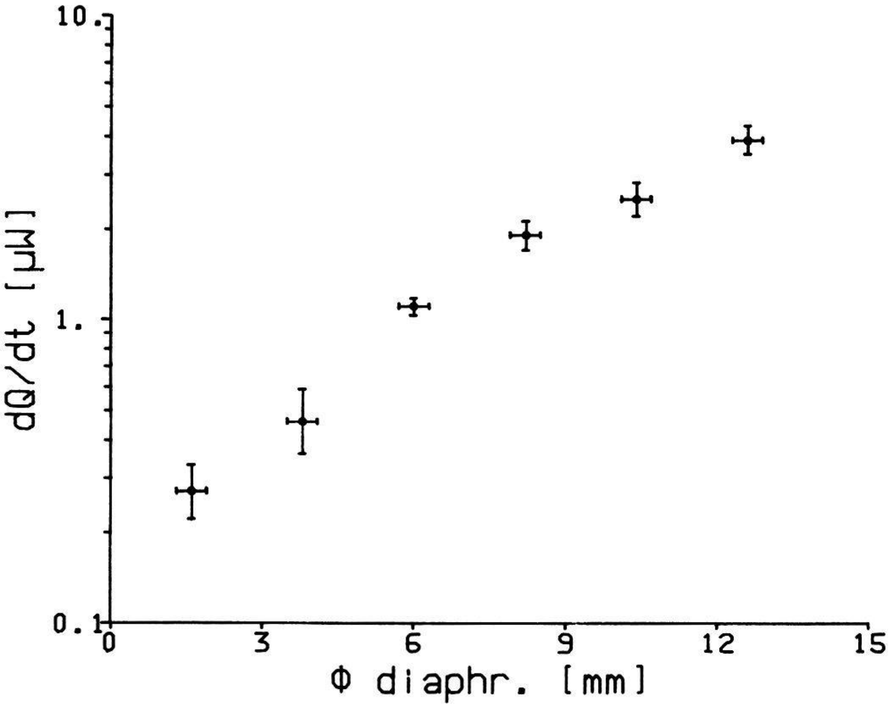

Fig. 2 Data points indicating the heat input to the sample holder as a function of the 77 K diaphragm diameter.

dilution unit (screw contacts).

Future plans include:

- the obtention of lower implantation temperatures by an increase of the cooling power (new type of dilution unit), and by decreasing the heat input of the side access using a movable diaphragm at 4 K.
- realizing higher beam transport efficiencies by a careful extension of the beam handling system.
- the introduction of a dynamical polarization system, in which microwaves are brought down to the sample holder through the top loading tube.

As a final remark in this section we indicate that the use of a refrigerator with side access should not be restricted to orientation of short living nuclei. In any application where a low temperature sample or its immediate environment must be reached, in a straight way, by a beam, electromagnetic radiation or mechanical items (e.g. cables), an adapted side access design may open up new possibilities. An application as a bolometer is investigated.

3. Production of polarized beams

It has been shown that a high degree of electronic polarization may be obtained in particle beams after anisotropic collisions. This polarization may be transferred to the nucleus by hyperfine interaction in the usual way. Transmission experiments (tilted foil techniques [1]) are restricted to light ions or high energy beams. Andrä has initiated the Ion Beam Surface Interaction at Grazing Incidence (IBSIGI) technique [2], where transmission is replaced by reflection from a surface. In general the obtained polarizations are higher than for tilted foil techniques, and the method is suited for low energy heavy ion beams, but at the expense of increased technical difficulties (surface quality, beam handling). A review is given in [3].

The same duality of techniques exists for another polarization principle, namely the pick-up of polarized electrons from a magnetized ferromagnet. The first transmission experiments were performed by Kaminsky [4], and the reflection geometry was first adopted by Rau [5]. The results obtained with this technique are limited to deuteron beams, in which electron polarizations of 100 % have been obtained in 100-150 keV beams.

Clearly an application of a beam polarization technique in our on-line nuclear orientation set-up requires the reflection geometry. It is our purpose to combine the IBSIGI with the pick-up of polarized electrons, by reflecting our mass separated beam on the <110> plane of a magnetized Ni single crystal. An optimal reflection angle of approximately 1° is expected. We hope to obtain in this way a "universal" polarized beam source, yielding much higher nuclear orientations than pure IBSIGI.

The technical difficulties to be overcome for the realization of this project mainly concern:

- the quality of the Ni single crystal surface, with minimal dimensions 15 x 50 mm^2 and extremely low granulation, to obtain good reflected beam qualities.
- the formation of a wedge shaped parallel incoming ion beam (width <1 mm).
- the realization of a suited ultra-high vacuum condition for the preservation of the surface qualities ($<5.10^{-10}$ mbar) within an isotope separator beam transport line.
- the impossibility to handle the outgoing neutral beam on his way to the target, since no re-ionisation scheme is presently envisaged.

Besides these, some difficulties of fundamental nature need to be solved:

- what target-temperature combinations may be used to maintain the nuclear polarization long enough?
- how strictly must the conditions of adiabatic weak field transition be fulfilled?

In the present status tests have been limited to the beam handling problem of incoming and outgoing beams, using a very flat Si surface. The prelimanary results show the profile of the reflected beam to have a FWHM ≈ 1.8° for an incidence angle of 2°. This shape is almost independent of mass and energy of the incoming beam. In the near future the UHV reflection chamber will be installed in front of the refrigerator, so that the distance Ni-crystal — cooled sample will be approximately 50 cm. The connection will be made through a specially designed side access, limiting the thermal heat input to around 500 μW. All detection of nuclear polarization will then occur in our standard mode, and very long polarization holding times are expected.

4. Conclusion

We have presented two schemes for the study of polarized short living nuclei, which complement each other with respect to the lifetimes that may be covered. This combination allows for adequate orientation of almost all isotopes produced at on line separators. The complementarity goes further, in the sense that the on line combination of a polarized beam and a polarized target facility (where the target may be prepared from the beam) may provide a unique tool to study polarization effects in nuclear reactions. Finally, it is obvious that the techniques which have been presented here may be applied successfully in high energy polarized beam or polarized target technology.

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