TESTS OF A LARGE AIR-CORE SUPERCONDUCTING SOLENOID AS A NUCLEAR-REACTION-PRODUCT SPECTROMETER

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ABSTRACT

An air-core superconducting solenoid, with a diameter of 0.2 m and a length of 0.4 m, has been configured for use as a heavy-ion reaction-product spectrometer ($E/A \leqslant 5$ MeV/u) near $\theta = 0°$ (10 to 35 msr). The performance of the spectrometer was established using α-particle sources and nuclear-reaction products from (^{18}O, ^{18}Ne), (^{18}O, ^{20}Ne) and (^{18}O, ^{14}O) and masses determined for ^{30}Mg, ^{108}Ru and ^{109}Rh. A system suitable for production of radioactive beams has been constructed, and in-beam tests are in progress at the University of Notre Dame. Large air-core solenoids with $d\Omega \geqslant 20$ msr and capable of focusing ions with $E/A \geqslant 30$ MeV/u appear feasible.

The ideal magnetic spectrometer for study of heavy-ion reactions would i) operate near 0° (0° to 30°); ii) focus heavy ions up to 50 or 100 MeV/u; iii) have a very large solid angle (> 20 msr); iv) have variable energy dispersion and magnification; v) have both long and short TOF flight path capability; vi) utilize high-resolution solid-state [ΔE, t, E, xy] detectors at the focal plane; and vii) have simple optics. A device which can satisfy most of these needs as a nuclear reaction product collector and filter is the superconducting-solenoid spectrometer.[1,2] A solenoid, when aligned at $\theta \approx 0°$, acts as a large-aperture, broad-range lens ($d\Omega > 20$ msr) with nearly isochronous, variable flight paths ($2 \text{ m} \leqslant \ell \leqslant 8$ m).

A 0.2 m bore, 0.4 m long, 3.5 T air-core superconducting solenoid magnet has been configured as an ion spectrometer as shown in Fig. 1, with the characteristics given in Fig. 2. Recent in-beam tests at ANL-ATLAS have utilized a (ΔE - t), (E - xy) solid-state telescope consisting of a large area (450 mm^2), planar, 28 μm thick silicon detector for ΔE and timing backed by a special 25 × 25 mm^2 two-dimensional position-sensitive silicon surface-barrier E detector 200 μm thick. This position-sensitive detector was developed at LBL[3] and utilizes a resistive anode for xy position readout. It has a position resolution of ⩽ 0.2 mm and 90 to 140 keV energy resolution for 8.78 MeV alpha particles. Position (xy) and E - TOF spectra, the latter gated via xy to limit the Bρ range, are displayed in Figs. 3

and 4.

The mass resolution of the spectrometer is limited by the non-isochronism versus θ, the kinematic shift versus θ, and the timing resolution of the accelerator and the detector. Like a dipole spectrometer, one can correct for kinematic shifts in energy (Fig. 5). With $\Delta t = 0.6$ ns typical of the silicon-detector system, one has $\Delta M/M \approx 1/50$ for a 2 m flight path.

Energy spectra for ^{26}Mg(^{18}O,^{20}Ne)^{24}Ne and ^{26}Mg(^{18}O,^{14}O)^{30}Mg are shown in Fig. 6 and 7. The energy accuracy (±150 keV) and resolution, typically ~1 MeV FWHM, were limited primarily by properties of the accelerator beam and somewhat by the solid-state telescope. Spectra for ^{110}Pd(^{18}O,^{19}F)^{109}Rh and ^{110}Pd(^{18}O,^{20}Ne)^{108}Ru were also obtained, the latter being one of the first direct observations of ^{108}Ru and establishing a mass for this neutron-rich nuclei. The mass excesses obtained are ΔM (^{30}Mg) = -10.32 ± 0.16 MeV, ΔM (^{108}Ru) = -83.95 ± 0.15 MeV and ΔM (^{109}Rh) =-84.24 ± 0.15. While these values are not particularly accurate, they were obtained during relatively short runs (1-2 hours) and illustrate the potential of this type of magnet for mass measurements.

A solenoid similar to the one used at ANL has been set up at the University of Notre Dame Tandem Van de Graaff facility to produce and focus secondary, radioactive beams at the focal plane. This spectrometer will be run in an asymmetric mode, with $z_{tgt} \approx 50$ cm and $d\Omega \approx 100$ msr (Fig. 2). With a production cross section of ~ 10 mb/sr and $d\Omega \approx 100$ msr we expect a ^{8}Li production rate of 10^5 to 10^6 ions/sec at the secondary focus. Preliminary tests are in progress.

The existing magnet is limited to $E/A < 6$ MeV/u. We propose construction of a large-bore, high-field, air-core superconducting solenoid with a 0.4 m bore, ca. 1 m long, and $B \geqslant 5$ T. Our design work indicates that such a magnet would be a very cost-effective system capable of focusing ions up to $E/A = 50$ MeV/u with solid angles of $d\Omega = 20$ to 800 msr. Alternately, one could use the magnet with its large bore as a very-long-flight-path TOF spectrometer for high-mass ions, e.g. fusion products. The very large solid angle possible with a 0.4 m bore magnet makes this magnet well suited as a secondary and radioactive beam collector. This work has been supported by NSF,DoE grants PHY-83-08072, PHY-86-05907, and W-31-109-ENG-38.

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[2] R. L. Stern, et al. Proc. Conf. on Instrumentation for Heavy-Ion Nuclear Research, ed. D. Schapira (ORNL Publ. Conf.-841005 -Absts., 1984), p. 95; R. L. Stern, et al., Rev. Sci. Instr. 58, 1682 (1987). R. L. Stern, Ph.D. thesis (University of Michigan, 1987) unpublished.

[3] J. Walton, LBL detector group

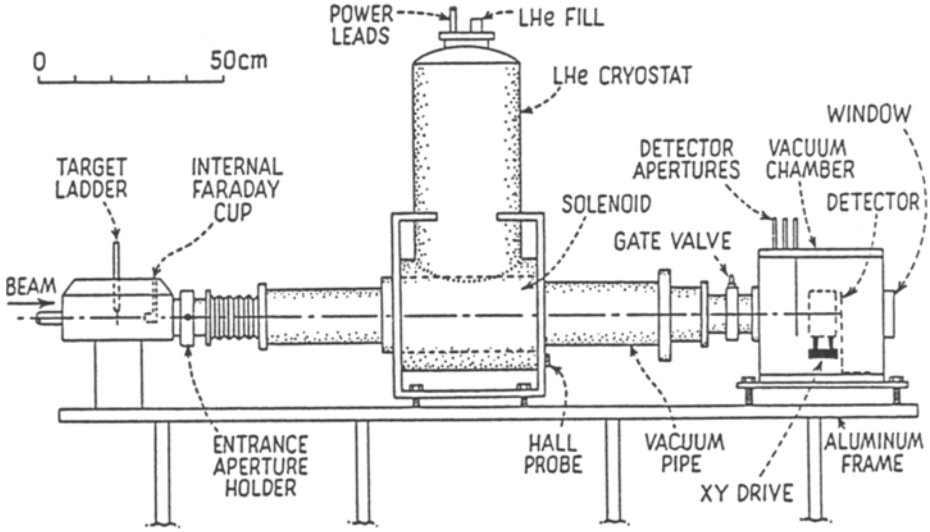
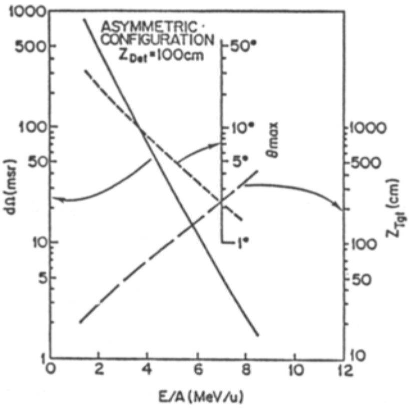


Fig. 1. Schematic diagram of the University of Michigan 0.2 m bore superconducting solenoid spectrometer.



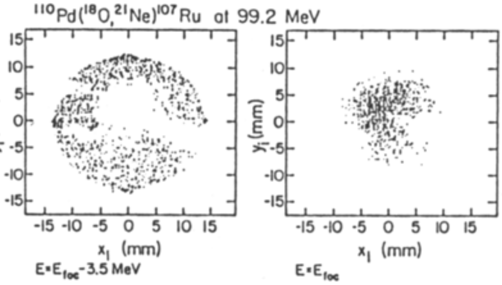


Fig. 2. Calculated solid angle vs. image and object distance and E/A for asymmetric configurations of the spectrometer. The energies are for non-relativistic ions with $q = Z = A/2$.

Fig. 3. Images of ^{21}Ne ions ^{18}O + ^{110}Pd. The ^{21}Ne ions are gated by windows 1 MeV wide in energy: a) $E = E_{foc} - 3.5$ MeV; b) $E = E_{foc}$.

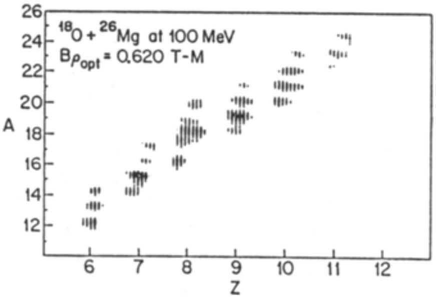


Fig. 4. An ion identification spectrum for 99.2 MeV ^{18}O + ^{26}Mg obtained with the silicon solid-state detector telescope.

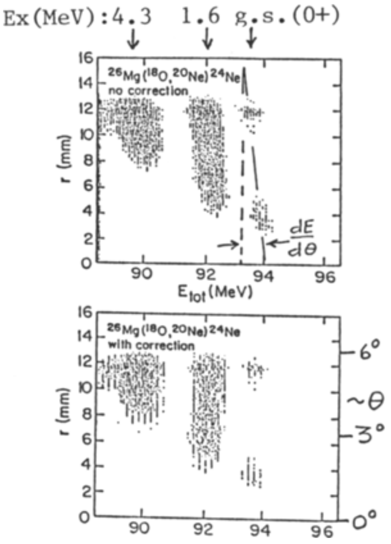


Fig. 5. E_{tot} vs. r for $^{26}Mg(^{18}O,^{20}Ne)^{24}Ne$ at Ebeam = 99.2 MeV before (top) and after (bottom) kinematic corrections.

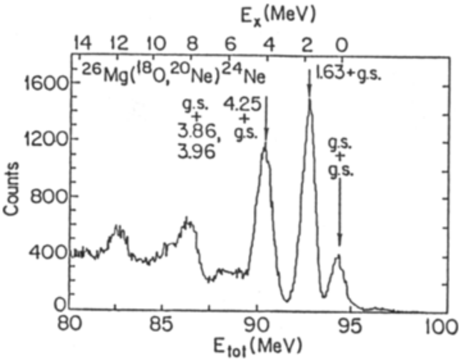


Fig. 6. Energy spectrum for $^{26}Mg(^{18}O,^{20}Ne)^{24}Ne$ at E_{beam} = 99.2 MeV.

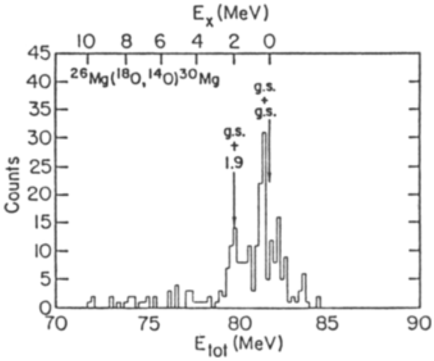


Fig. 7. Energy spectrum for $^{26}Mg(^{18}O,^{14}O)^{30}Mg$ at E_{beam} = 99.2 MeV.