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ACCELERATION OF HEAVY IONS IN THE AGS*

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Summary

It is possible to use the Brookhaven AGS as a heavy ion machine by adding a cyclotron to the Tandem and using this combination as injector. An intermediate step for lighter ions might consist of injecting the Tandem beam directly into the AGS. In either case, quite high intensities should be possible.

There is an increasing interest in the accelerator of heavy ions to relativistic energies. The physics questions to be addressed by such beams range from continuation of current nuclear structure studies to the formation of exotic quark-gluon plasma states. The Brookhaven AGS would be an interesting machine to be used for this physics if it were fitted with a suitable injector.

Modern state of the art accelerator technology suggests that an appropriate injector might consist of:

1. An electron beam ion source (EBIS) or electron cyclotron source (ECS) to produce ions in a high charge state.
2. Several stages of linear accelerator including radio frequency quadrupole (RFQ), Widerøe, Alvarez, and/or discrete cavity structures.
3. Some kind of circular "booster" to raise the ion energy enough to strip to a very high charge state, preferably the fully stripped state.

Such an injector is unlikely to be built. There is no need for the intensity that is made possible by this complex and the cost is prohibitive.

For the past several years, the Brookhaven Nuclear Physics group has considered the possibility of adding a cyclotron to the present Tandem accelerator. As part of the proposal submitted last year to the funding agency,⁽¹⁾ it was shown that this Tandem-cyclotron combination forms a quite suitable injector for the AGS. The performance of this combination can be estimated from several simple arguments. The Tandem-cyclotron is expected to deliver currents of ≥ 600 particle nano amps of fully stripped ions at energies ≥ 70 Mev/amu up to mass ~ 130 (say 127). Performance at lower mass numbers can be expected to be significantly better. The minimum AGS intensity can then be determined by simple scaling. The AGS has delivered 10^{13} protons per pulse using an injected beam of 60 ma. We should, then, expect about 10^8 ions per pulse with the 127 beam. This is quite a respectable ion intensity; it may be too high! Actually, the cyclotron beam should have about two orders of magnitude smaller emittance and one order of magnitude less energy spread than the usual proton beam. If these features were properly used to advantage, the intensity could be much higher.

This concept is based on using fully stripped ions so no significant improvement of the AGS vacuum

(10^{-7} Torr) is implied. A new vacuum system, which may not be prohibitively expensive, would permit acceleration of ions up to U^{238} if that need were ever demonstrated.

As an intermediate project, it appears possible to accelerate ions of mass up to about 30 (say S^{32}), using only the Tandem.⁽²⁾ The pulsed current capability of the Tandem has been demonstrated to be about 60 particle microamps so, from our simple scaling, intensities in excess of 10^{10} ions per AGS pulse can be expected. Such intensities are not space charge limited. The magnetic rigidity is low but only 20% lower than the AGS design for 50 Mev proton injection as was used for several years. Preliminary magnetic measurements indicate good field over an adequate aperture.

The only serious technical problem with these schemes lies in the rf system. Because of the low velocity at injection, ions require more frequency change during acceleration than is possible with the AGS rf system. The solution would be to capture and accelerate the beam from the cyclotron using the 24th harmonic instead of the usual 12th harmonic until the velocity is about half the speed of light. The magnet would be stabilized, the beam adiabatically debunched then rebunched on the 12th harmonic. The remainder of the acceleration could then proceed just as for protons. This process has been demonstrated at CERN where it has been used for alpha particle acceleration in the CPS.⁽³⁾ For Tandem injection, the harmonic jump would be invoked twice with initial capture on the 48th harmonic.

The following table summarizes the options for ion acceleration in the AGS:

Option	Maximum A	Energy	Intensity
Tandem	32	15 Gev/amu	$\sim 10^{10}$ - 10^{11} ion/pulse
Cyclotron	130	12.5 Gev/amu	$\sim 10^8$ - 10^9 ions/pulse
Cyclotron and new vacuum	238	≥ 9 Gev/amu	$\sim 10^7$ ions/pulse

The original AGS scheme⁽¹⁾ was developed by Lyle Smith. Roy Thern has been responsible for the magnetic measurements for fields corresponding to Tandem injection. A number of colleagues have assisted in this study. Particular thanks go to Chellis Chasman for his diligent attention to details about the Tandem performance, cyclotron performance, and special problems associated with very low velocity ions in the AGS vacuum.

(1) Proposal for a Heavy Ion Facility at Brookhaven, BNL Informal Report 30630 (unpublished) 1982.

(2) Proposal for a 15A Gev Heavy Ion Facility at Brookhaven, BNL Informal Report 32250 (unpublished) 1983.

(3) P. Asboe-Hansen, et al., IEEE Trans. on Nucl. Sci. NS-24 #3, 1557-1560 (June 1977).

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