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ACCELERATION OF HEAVY IONS IN THE AGS

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ACCELERATION OF HEAVY IONS IN THE AGS

For the sake of curiosity, the acceleration of helium and some heavier nuclei (N,O,Ne) in the AGS has been considered. Deuteron acceleration in the AGS has been described by J.G. Cottingham,¹ Th. Sluyters,² and S. Ohnuma and Th. Sluyters;³ deuterons were successfully accelerated at BNL,³ using only the first tank of the linac in the 4π mode, up to the final energy of 5 MeV or 2.5 MeV/nucleon. In the last paper it has also been shown that tanks #2 and #3 could be used to accelerate deuterons further, to the energy of 30.61 MeV or 15.3 MeV/nucleon. It was further proposed,² that an additional cavity be put into the main ring, with a lower minimum frequency to allow for the lower injection energy. The acceleration in the main ring would then proceed by using this cavity first (or cavities, if more than one is needed), with the harmonic number $h = 24$. The frequency range for this first stage would be approximately 1.5 - 4.8 MHz, corresponding to an energy range of 15 - 180 MeV/nucleon. After reaching the upper limit of the first stage, the beam would be debunched with $B = \text{const.}$ and again captured with the present rf system at $h = 12$. The acceleration would proceed to the final energy of about 15 GeV/nucleon.

It will be assumed that heavy ions can be accelerated in the main ring the same way as deuterons. No calculations will be done concerning the parameters of the rf system or vacuum requirements.

a) He^{2+} ions. Although some standard ion sources may yield as much as 15% in the He^{2+} state, available currents are usually below 1 mA. Therefore,

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1. J.G. Cottingham, AGS Tech. Note No. 86, August 1971.
 2. Th. Sluyters, AGS Tech. Note No. 94, June 1972.
 3. S. Ohnuma and Th. Sluyters, Proc. 1972 Proton Linear Accel. Conf., Los Alamos.

a direct production and acceleration of He^{2+} ions in the present Cockcroft-Walton preinjector would yield very low beam currents of high energy α -particles. A higher intensity may be obtained by accelerating He^+ ions first and then stripping them to He^{2+} . The stripping foil would be placed in the LEPT. Total energy of so obtained He^{2+} ions would be 750 keV, which is the proper energy for injection into the first tank of the linac, operating in the 4π mode.^{2,3} The stripping efficiency⁴ for helium ions at an energy of 750 keV is about 60%. At the end of the linac tank #3 α -particles would have an energy of 15.3 MeV/nucleon and would be injected into the main ring, at $B \approx 130$ G.

b) N^{7+} ions. Direct production of these ions in a source is very inefficient and stripping has to be used. However, partially ionized atoms when passing through the stripper, have to have a rather high energy (several MeV per nucleon) if an appreciable yield of fully stripped ions is desired. Ions of such a high energy cannot be injected and captured in the first tank of the linac. If the 4π mode in the linac is still to be applied, then the first tank could be by-passed and only tanks #2 and #3 used. Energy at the entrance to the second tank should be 2.57 MeV/nucleon,³ which is sufficient for full stripping. The problem is how to obtain nitrogen ions of 36 MeV total energy.

Assume that a tandem is used as the preinjector. Nitrogen ions in the charge state $4+$ would be extracted from a source in the terminal (standard Penning-type sources yield up to 10% of the extracted beam in this charge state, or about 1 mA; if higher intensities are desired a double stripping would be necessary as described for neon ions). The terminal voltage required for a total energy of 36 MeV is 9 MV; at this energy about 60% of ions leaving the stripper would be fully stripped.⁵ Acceleration in tanks #2 and #3 would increase the energy to 15.3 MeV/nucleon or 215 MeV total.

c) O^{8+} ions. Oxygen ions could be produced in a source on the ground as O^+ , accelerated by the terminal voltage V , stripped in a gas cell in the terminal to the charge state $5+$, accelerated again to the final energy of $(1 + 5) V = 6 V$ [eV] and fully stripped in the LEPT. As the total energy of oxygen ions has to be about 41 MeV after leaving the tandem, the necessary terminal voltage is about 7 MV. At 7 MeV total energy the most probable charge state of an oxygen ion after passing a gas stripper is $5+$; stripping to $7+$

4. S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958).

5. H. H. Heckman, et al., Phys. Rev. 129, 1240 (1963).

at an energy of 42 MeV is not that efficient; only about 35% of ions would become fully stripped.⁵

d) Ne^{10+} ions. Neon ions require a higher terminal voltage and a more complex mode of preacceleration than nitrogen ions. Assuming again that only tanks #2 and #3 are used in the 4π mode, the total energy of fully stripped neon ions at the entrance to the linac has to be about 52 MeV. Even with a terminal voltage of 10 MV an initial charge state of $5+$ would be required, which is practically out of reach of present ion sources. However, solutions other than a much higher terminal voltage do exist. Neon ions can be extracted from the source in the $3+$ state, accelerated to a total energy of 9 MeV, stripped to a charge state $6+$ with a foil placed in the column itself and accelerated to the final energy of 52 MeV. The necessary terminal voltage is about 10.2 MV, stripping foil is placed at the 3 MV level ($3 \times 3 + 6 \times 7.2 \approx 52$). Efficiency of the stripping $6+ \rightarrow 10+$ at an energy of 52 MeV is about 15% and the overall efficiency $3+ \rightarrow 10+$ about 4 - 5%.

Intensities of accelerated ions would depend on the source and stripper performance. It can be expected that of the order of 10^{12} α -particles and of the order of 10^{11} heavier nuclei per pulse could be obtained. It might be of interest to note that nitrogen and neon ions with an energy of several hundred MeV per nucleon have been considered in radiation therapy.⁶ This energy could be reached by using the first stage of rf acceleration in the main ring. The final energy of all ions considered in this note would be 15 GeV/nucleon, or 60 GeV for α -particles, 210 GeV for nitrogen ions, 240 GeV for oxygen ions, and 300 GeV for neon ions.

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6. Proc. Conf. Particle Accelerators in Radiation Therapy, Los Alamos, Oct. 1972 (LA-5180-C)