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ACCELERATOR DEPARTMENT
(AGS)
Internal Report

MASTER

ACCELERATION OF DEUTERONS OR ALPHA PARTICLES IN THE AGS

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I. Possible Experiments with High-Energy Deuterons and other Nuclei.

The magnetic field of the AGS ring can contain particles of magnetic rigidity about 34 Bv/c. This includes not only protons of kinetic energy 33 Bev, but also 32 Bev deuterons, 64 Bev alpha particles, and conceivably heavier nuclei such as 188 Bev carbon nuclei. It will be shown in this paper that such nuclei can be injected and accelerated in the AGS if some rather small modifications are made in the injection and acceleration systems.

What physics could be done with such beams? Several types of experiments may be suggested. In the first place, since the deuteron is a rather loosely bound combination of a neutron and a proton, it is likely to break up when it hits a target nucleus (stripping reaction). In a considerable fraction of the collisions the neutron will go straight on with essentially unchanged energy (half the deuteron energy). Therefore, with an internal target bombarded by 30 Bev deuterons one should obtain an intense, rather well collimated and monochromatic beam of 15 Bev neutrons in the forward direction.

This stripping reaction is well known in the range up to 300 Mev; much of the early work with the Berkeley 184-inch cyclotron was done with such a neutron beam. The main reason why this was not done more

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extensively was probably that 150 Mev neutrons are not energetic enough to make mesons; with 15 Bev neutrons one can make everything that can be made with 15 Bev protons, and one can then study the same reactions in different isotopic-spin states than are available with proton bombardment.

As an example of the interesting physics that can be done with neutron beams, one may consider the recent experiment by Palevsky*, in which the angular distribution of forward charge-exchange scattering of 2 to 3 Bev neutrons or protons was observed. The result - a very narrow forward peak - is non-tribal, to say the least. Palevsky's neutrons were obtained by charge-exchange scattering of protons. It is not likely that this process would produce an adequate neutron beam for similar experiments at higher energies, but deuteron stripping would.

Other experiments could be done with an extracted deuteron beam (the external beam system would work the same with deuterons as with protons). Since the deuteron has $T = 0$, $J = 1$, we can again single out different spin and isotopic-spin than with single nucleon bombardment. The same is true if alpha-particles ($T=J=0$) are used instead of deuterons. In addition, a study of the details of the stripping process at high energy, and comparison of P-X, N-X and D-X reactions, would provide information about the binding forces in the deuteron.

Finally, if heavier nuclei such as Li^6 , B^{10} , C^{12} , etc. could be accelerated, one could duplicate in the laboratory some of the heavy primaries of the cosmic radiation; this might lead to better calibration

*H. Palevsky et al., Phys. Rev. Letters, 9, 509, (1962)

of the properties of these primaries.

II. Injection.

The AGS linear accelerator is built to accelerate protons from a velocity $0.04c$ to $0.315c$. The velocity at any point is determined by the spacing of the drift tubes. Deuterons could, in principle, be accelerated through the same range of velocities. But in order to do this one would need twice the accelerating electric field (four times the rf power) needed for protons; this is out of the question with the present linac.

There exists, however, another mode of acceleration, in which the velocity at any point is half that of protons accelerated to that point. In this mode the particle spends two rf cycles between accelerating gaps instead of one. The particles therefore emerge with $\beta = 0.158$ instead of 0.315 ; deuteron energy = 25 Mev.

An analysis* of this mode of acceleration shows that deuterons can indeed be accelerated this way to 25 Mev with very little if any readjusting of the linac. The major change necessary is that the Cockcroft-Walton preinjector has to be at 375 kv instead of 750 kv. All magnetic focusing elements between the linac and the ring would be unchanged; the inflector voltage would have to be halved.

Exactly the same conditions are necessary for accelerating alpha particles, or completely stripped heavier nuclei with $Z/A = \frac{1}{2}$, to the same velocity of $0.158c$. (However, the stripping has to be complete; this would necessitate rather elaborate ion sources if nuclei as heavy as carbon are to be accelerated.)

*E. D. Courant, Proceedings of Conference on Linear Accelerators, BNL, 1962, p. 289.

The magnetic field at injection would be the same as with protons, i.e., about 120 gauss.

III. Synchrotron Acceleration.

The relation between magnetic field and frequency is different from particles of different e/M , but the same for the same e/M . Therefore, the r-f program for deuterons, alpha particles, and heavier $Z = A/2$ nuclei has to be the same. In what follows we shall refer only to deuterons for the sake of brevity; however, everything also applies to the heavier particles.

To accelerate deuterons in the AGS from 25 Mev to 30 Bev, the r-f program will have to accommodate a range of velocities from about .158c, rather than .315c to c as for protons. Therefore, if we wish to stay within the bandwidth of the present accelerating system (1.4 to 4.5 Mc), we will have to jump from one harmonic order to another. We may start at the 24th harmonic; at injection this is just equal to the 12th for protons. Then, at a time when both the 12th and 24th harmonic lie within the permissible bandwidth, we must change to the 12th harmonic and continue on the 12th for the rest of the acceleration cycle.

The time at which this must occur, determined by the condition

$$\beta \leq 1/2$$

since the 24th harmonic must lie below the top frequency of the band, and

$$\beta \geq 0.315$$

since the 12th harmonic must lie above the bottom of the band.

Several approaches may be suggested. The simplest may be the following:

Bunch the injected beam with the starting oscillator and lock on to beam control with the 24th harmonic (same frequency as for proton acceleration).

Accelerate until twice the injection frequency is reached. Then put a flat step into the magnet voltage for a few milliseconds.* Turn off the rf; the beam will coast and debunch. At the same time the cavities must be retuned to 1.4 mc. Then rebunch with starting oscillator; phase lock on 12th harmonic, and resume acceleration. The transfer efficiency should be about the same as the initial capture efficiency, i.e., optimally about 75%.

In the first stage of acceleration (24th harmonic) all cavities have to be in phase, rather than half of them at 180 degrees with respect to the other half. For the second stage (12th harmonic) the phases are as in proton acceleration. However, six cavities should be adequate for the first stage of acceleration, since it all takes place before $\dot{B}$ increases.

The main changes to the AGS rf system are in the low-level controls. We need systems to do the following:

1. Disable (or reverse) those cavities which are at position 10 of a superperiod during the first (24th harmonic) stage of acceleration; turn them on again (or reverse phase) for second stage.

2. Turn off accelerating voltage at beginning of flat step.

3. Reset starting oscillator after injection; sweep it again (possibly with reduced df/dt) at end of flat step.

4. During flat step, retune all cavities to starting frequency.

Then turn on cavity voltage, feeding starting oscillator signal to cavities.

*This can be done with the present flattop circuitry or a simple modification thereof.

5. After a short time ($\sim 100\text{-}200\ \mu\text{sec}$) on starting oscillator, switch to beam control.

6. Transition must be set to 14 Bev.

IV. Suggested Preliminary Experiments.

Some, though not all, of the features of the deuteron accelerating system suggested here can be tried out with the AGS as it is now.

The acceleration of deuterons in the linac can be simulated by using hydrogen molecular ions (H_2^+), which are always formed in a proton ion source whether we like it or not. Simply set the Cockcroft-Walton at 375 kv and see whether a beam comes out of the linac. If the inflector is then set at half voltage, this beam will also be injected into the AGS ring.

To accelerate this beam one requires just the same starting oscillator frequency as for protons. However, the cavities would all have to be in phase, while at present five cavities (B, C, D, J, K) are 180° out of phase with the other seven. If these cavities were locked out, the remaining ones would provide $7/12$ of full voltage, enough for bunching and preliminary acceleration. Or three cavities could be locked out, providing $5/12$ of full rf voltage.

However, the H_2^+ ions would not last long in the ring, because they would be dissociated, probably in a few milliseconds, by the magnetic field and also by collisions with residual gas molecules. To maintain 24th harmonic acceleration for any length of time one needs deuterons or alpha-particles.

The flat step can be tried right now using the existing flattop circuits. If rf is turned off at or near the beginning of the flat step, the beam will debunch but continue to circulate; one could observe this debunching process. This can be done with protons accelerated in the usual way.

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The rebunching cannot be done with protons unless we have a second starting oscillator running at twice the frequency of the existing one.

The whole process of harmonic jumping may, however, possibly be tried with protons. We may accelerate protons in the linac to 12.5 Mev using the half - velocity mode (Cockcroft-Walton at 187 kv; linac level down to about half of normal voltage; all focusing magnets including linac quadrupoles at half of normal currents; inflector at one-fourth normal voltage). The injection field will be half normal, i.e., 60 gauss. We may then accelerate on the 24th harmonic, using the normal starting oscillator and all cavities except B, C, D (giving $5/12$ of full rf voltage). Accelerate to the flat step, which should come just at normal injection time. After turning rf off and debunching, we may then attempt to recapture the beam in the normal manner and accelerate normally with nine cavities (which will now give $9/12$ of full voltage, enough for full acceleration, though somewhat inefficient).

V. Conclusions.

The modifications necessary to convert the AGS to acceleration of deuterons or heavier particles do not appear to be prohibitive. Some experiments designed to verify that this scheme will work can be performed now. The modification would make possible a whole new class of particle physics experiments. I propose that this possibility be studied seriously.

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