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POLARIZED DEUTERONS AS AN INTENSE SOURCE OF HIGH-ENERGY POLARIZED BEAMS OF NEUTRONS, PROTONS, AND DEUTERONS

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1. GENERAL CONSIDERATIONS

The difficulty in accelerating polarized protons up to a high final energy without depolarization is well known[1,2]. In the c.m. of the accelerated particle, superperiodic, betatron, and synchrotron oscillations induce oscillating transverse magnetic fields, which can rotate the polarization. Such depolarizing effects exist only at very definite frequencies for which there is a resonance between the frequency of these magnetic fields and the proper transverse frequency of the magnetic moment of the particle. The spin frequency in the c.m. is given by

$$\left(\frac{g}{2} - 1\right) \times \gamma \ , \tag{1}$$

$[(g/2) - 1]$ being the anomalous part of the magnetic moment, and γ, as usual $= E_{\mathrm{lab.}}/mc^2$. The equation for the resonance is:

$$\left(\frac{g}{2} - 1\right) \gamma \not{\nu}_c = \not{\nu}_c (kS + \ell Q_r + mQ_z), \tag{2}$$

S being the superperiod of the machine, Q_r and Q_z the number of radial and vertical betatron oscillations per turn, and (k,ℓ,m) integers. For a given (k,ℓ,m) combination, the right-hand side of Eq. (2) is almost constant, and the left-hand side grows up from $\sim [(g/2) - 1]$ to $[(g/2) - 1]\gamma_{\mathrm{max}}$. For the PS, one can write

$$\left(\frac{g}{2} - 1\right)\gamma = 10k + (\ell + m)Q + (\ell - m)\Delta Q \ , \tag{3}$$

where $Q_z \approx Q_r \approx Q \cong 6.3$ and $2\Delta Q = (Q_z - Q_r) \approx$ small.

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polarized neutrons, deuterons, and protons. Even losing ~ 2 orders of magnitude over the primitive deuteron pulse in order to improve the "quality", there remain enough neutrons, protons, or deuterons to do physics.

That the nucleons are and remain polarized is a matter of fact. The deuteron is essentially an s-wave, and a (±1) vector polarization of the deuteron means ~ (⇈) or (⇊) for the individual nucleons. When a nucleon is absorbed, the residual one suffers only a small-angle scattering for which the depolarization parameter $D(\vartheta)$ is very near 1:

$$P_f = \frac{p(\vartheta) + dP_i}{1 + p_\vartheta P_i}$$

$p(\vartheta)$ being the polarization "created" in this small-angle scattering, and for the whole secondary beam

$$\langle P_f \rangle \cong \left\langle \frac{p(\vartheta) + d(\vartheta)\, P_i}{1 + p(\vartheta)\, P_i} \right\rangle_{\Theta = 0,\ \varphi = 0}^{\Theta_{max},\ \varphi = 2\pi} \sim \bar{d} P_i \sim P_i = \pm \frac{2}{3} .$$

[The very expression, averaged over Θ and φ, depends on the (D,R,A) parameters; but the result $P_f \sim P_i$ is essentially unchanged.] The polarization of the deuteron, as well as of the remaining p and n, can be reversed, burst after burst, before acceleration. This is simply done in ~ 2 μsec at the level of the atomic beam, before ionization, by cutting off the radio-frequency systems inducing transitions between Zeeman sublevels of the deuterium atoms. Is it realistic to hope for 10^{10} deuterons/pulse? The best intensity$^{4)}$ after ionization is now of a few microamperes d.c., say 2×10^{13}/sec. With a time acceptance of 6×10^{-6} sec, and a trivial reduction factor through the Linac, it seems difficult to hope for better than a few times 10^7/burst. But it should be noted that:

i) a few hundred microamperes d.c. could be obtained with actual polarized atomic sources; it is enough to say that at Saclay we have such an improvement programme (essentially at the level of the ionization of the atomic beam);

ii) bunching at low energy (before the Linac) can provide some trivial factor by increasing the total number of protons in the $\Delta t = 6 \times 10^{-6}$ sec (one turn capture in the PS);

iii) with such an intensity, smaller than the usual one, the beam loss in the Linac should also be smaller and the capture efficiency better.

A FEW REMARKS

1) All that was proposed using an external target is also possible with an internal target -- except that the residual deuteron beam would remain in the machine. Neutrons would go "naturally" outside, and the protons inside the ring.

2) By storing the deuterons in one storage ring, and crossing this beam with an atomic polarized beam ($\lesssim 10^{12}/\mathrm{cm}^3$), this can provide a very clean experiment (d- p) with all spins polarized in all possible relative directions (and d- d also).

3) If our first point demonstrates the practical impossibility of accelerating polarized protons up to full energy, then last but not least there remains the possibility (to be investigated!) of polarizing protons inside the storage rings, after storing them unpolarized. The principle would be a "transfer of spin" with some polarized materials. In such a case, the full intensity would be available. But this is a very preliminary suggestion. A few possible "materials" are being investigated.

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