理研シンポジウム

スピン偏極低速陽電子ビ　ムの基礎と応用

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Possibilities for a high intensity polarized slow positron source using ^{13}N

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ABSTRACT - A small area intense polarized beta-decay positron source could be made using the reaction $^{12}C(d,n)^{13}N$, provided the activity were transported away from the deuteron target by a carrier gas and frozen onto a small diameter spot. 60 kW of 15 MeV deuterons could yield a source of 3×10^{10} slow polarized positrons per second from a 100 μm source spot. Such a source would be as effective as a pulsed LINAC source of equal power, and would be equivalent for high brightness applications to a 10 cm diameter 300 kCi ^{64}Cu source.

INTRODUCTION - Polarized positrons are useful for probing the spin density of electrons in solids [1] and for studying positronium and its chemistry [2]. Various experiments using high densities of positrons can also exhibit the mysterious spin one-half of the positron and the Fermi statistics this entails. No one would believe the spin-statistics connection should fail for anti-matter, especially since it is at the heart of the amazingly successful qed theory [3]. However, it would be informative to directly observe positron Fermi statistics and possible interesting departures from non-interacting particle behavior. For example, one could study the dynamics of Ps_2 molecule formation at a solid surface, the effects of small perturbations on the Bose-Einstein condensation of spin polarized Ps and of Ps_2, correlation effects on the negative work function emission of high density positrons from a solid and possible positron superconductivity and magnetic ordering in solid insulator hosts.

Collections of positrons sufficient in number and low enough in temperature for displaying Coulomb correlation effects are already available in magnetic traps [4], and the trapped positrons may be polarized using resonance techniques [5], if they are not initially polarized. On the other hand, β decay positrons are polarized if they are velocity selected, and an intense polarized positron source would find many uses [6].

Candidates for a large polarized positron source include the β decay sources ^{64}Cu, ^{79}Kr and ^{58}Co, all of which suffer somewhat from difficult preparation requirements associated with a nuclear reactor and physical and chemical manipulations. A short lived isotope produced by charged particle bombardment of light elements is a possible alternative to a reactor source [7]. The present note describes a scheme for the production of slow positrons from ^{13}N, made via the $^{12}C(d,n)^{13}N$ reaction [8], that might be suitable for an intense polarized source.

The thick target yield of ^{13}N for a given power is almost constant for d energies between 10 and 30 MeV [9]. The peak yield is 2×10^{13} ^{13}N/s or about 500 Ci given 60 kW of deuterons at 15 MeV. My present slow positron beam uses 50 mCi ^{22}Na behind a 5 μm Cu(2% Be) window, an Ar moderator and a conical moderating surface to give 3×10^{6} slow e^+/s. Extrapolating to a 10^4 times stronger source suggests that a 60 kW ^{13}N source could yield 3×10^{10} slow e^+/s.

SUGGESTED DESIGN - A possible way to make use of the ^{13}N is suggested in Fig 1. The important features include using a large area (and therefore easily cooled) hot porous carbon target from which ^{13}N is to be continuously extracted by means of a carrier gas consisting of He with possibly a trace of ordinary N_2 to act as an exchange agent. The ^{13}N is to be transported away from the harsh environment of the d target region and condensed in a small area on the back of a cold (10 K) thin (50 μm) diamond window. Note that 500 Ci of ^{13}N would dissipate about 2.5 W in the window, which, given the 100 W $cm^{-1}K^{-1}$ thermal conductivity below 100K, would lead to a few K temperature rise in a 100 μm diameter spot. The slow positron moderator could thus be a solid rare gas [10] or possibly a field-assisted diamond moderator [11].

The smallest practical size of the condensed ^{13}N spot is determined by the geometry of the smallest nozzle that just provides sufficient pumping speed S to extract the gases from the irradiation cell of volume V in less than the 10 min ^{13}N half life. For a simple orifice of diameter d, the evacuation time constant is $\tau = V/S \approx 8V/d^2$, where d is in mm, V is in liters and τ is in sec. With V = 0.1 l and $\tau < 10^3$ s, the orifice diameter must be greater than 30 μm.

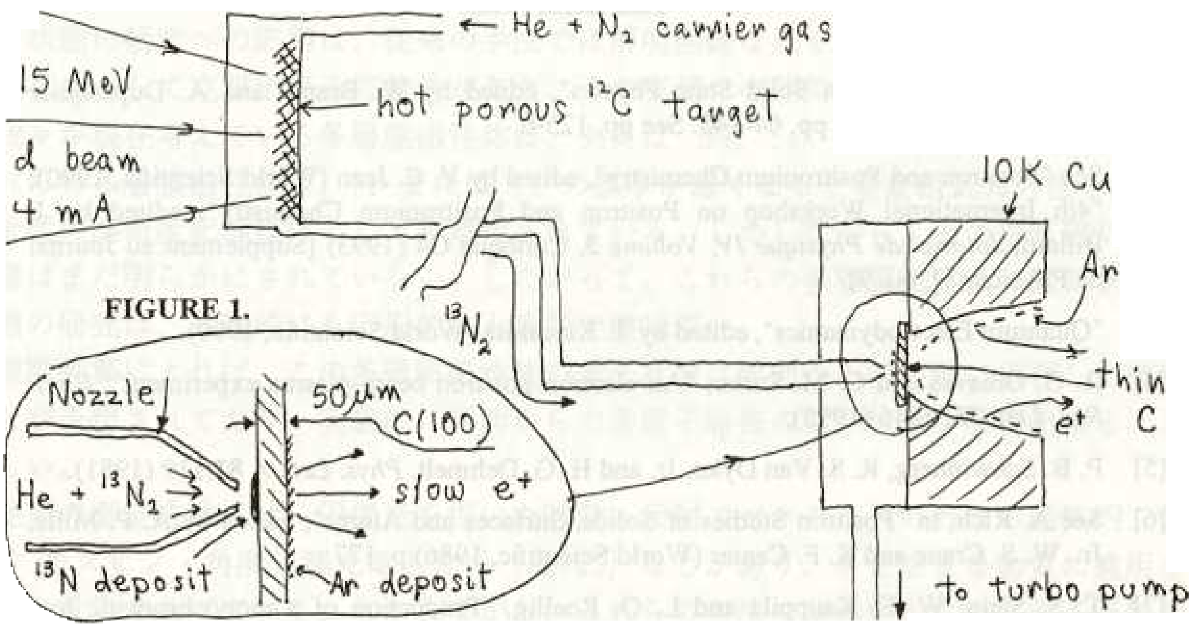

FIGURE 1.

BRIGHTNESS CONSIDERATIONS - The possible great positron beam brightness resulting from a less than 100 μm diameter ^{13}N spot would make such a source more valuable for many purposes than a much stronger source originating from a larger area. For example, if high beam brightness is a requirement, then each stage of brightness enhancement [12] typically [13] reduces the beam diameter by a factor of 10 and the intensity by a factor of 5 while giving 20 times more brightness. A 100 μ ^{13}N source of 3×10^{10} slow e^+/s would thus have the equivalent brightness available from a 300 kCi ^{64}Cu source 10 cm in diameter. The position of the source spot would have to be changed every 10 m to avoid excessive build up of ^{13}N and ^{13}C.

It is to be noted that a pulsed beam from a LINAC has a high density in phase space that may be turned into a small diameter continuous beam if desired by capturing a pulse in a trap and letting the positrons leak out slowly through a small diameter potential hole. Some scrambling mechanism would be needed to make the transverse trajectories ergodic or chaotic; probably the Coulomb interactions would suffice given a large number of stored positrons [14]. Existing pulse stretchers [15] that let the positrons escape past a transversally uniform potential may be used to achieve the complementary effect of a very narrow beam energy spread. If the duty cycle is η = pulse length x repetition rate, then either the beam area or the energy spread may be reduced by the factor η in principle. Thus, a typical LINAC beam that might be 1 cm in diameter and have $\eta < 10^{-6}$ would have a brightness equivalent to a 10 μm continuous beam of the same energy. If the positron trap were in a high magnetic field and contained a cavity tuned to the spin flip frequency and coupled to a cold (4 K) load, the positrons from an unpolarized LINAC source may be spin polarized also. The spin cooling time is roughly 1 sec$\times(50\text{kG}/B)^2\times(1/Q)$, where Q is the "Q" of the resonant cavity. In calculations of the relative merit of different designs, the cavity polarizer has the disadvantage of using a large magnetic field, into and out of which the positrons must be transported adiabatically to preserve the brightness.

We conclude that a ^{13}N source as describe herein could in principle be much better than any practical reactor-produced isotope source. On the other hand, a pulsed LINAC positron beam could be roughly equally valuable as a ^{13}N source of the same primary power, and the choice of which one to use would depend mostly upon cost and other non-technical factors.

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