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Activation reaction $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}$ as a spin analyzer for fast neutrons

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It is shown that ^{12}B nuclei produced in the $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}$ reaction are polarized. The polarization of ^{12}B is measured through its beta-decay asymmetry. The analyzing "efficiency" $\epsilon = P_N/P_n$ (^{12}B polarization versus that of the incident neutron) for longitudinally polarized neutrons of average energy $\bar{E}_n = 18$ MeV is: $|\epsilon| = 0.11 \pm 0.02$.

[NUCLEAR REACTIONS $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}(\beta)\,^{12}\mathrm{C}$; $E_n = 18$ MeV; measured β-decay asymmetry; deduced ^{12}B polarization and analyzing efficiency.]

INTRODUCTION

This paper is a report on the use of the activation reaction $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}$ as an "analyzer" for the polarization of fast incident neutrons. The signal, i.e., the resulting beta-decay asymmetry in $^{12}\mathrm{B}(\beta^-)^{12}\mathrm{C}$, is determined *after* the activation period. A description of this kind of neutron polarimeter is given and its "efficiency" $\epsilon = P_N/P_n$ (^{12}B vs n polarization) for longitudinally polarized neutrons of average energy $\bar{E}_n = 18$ MeV is determined by using for calibration the reaction $^2\mathrm{H}(\alpha,\vec{n})\alpha p$.

The use of an activation reaction as an analyzer for the neutron polarization has already been suggested, at least implicitly, by Burgy *et al.*[1] These authors observed that ^{8}Li produced in the capture of polarized *thermal* neutrons by unpolarized ^{7}Li are quite highly polarized. The polarization of ^{8}Li, which is a "short" lived beta emitter ($\tau = 1.2$ s), was measured through its decay asymmetry.

The choice of the $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}$ reaction and that of the carbon target are explained in Sec. I. The polarized neutron beam and the polarimeter are described in Secs. II and III, respectively, and the result obtained for ϵ is given in Sec. IV.

I. THE $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}$ REACTION AND THE CARBON TARGET

The choice of the $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}$ reaction is motivated by two properties: (i) the lifetime of ^{12}B is short (30 ms) and (ii) the β-ray energy in $^{12}\mathrm{B}(\beta^-)^{12}\mathrm{C}$ is large [$E_\beta(\mathrm{max}) = 13.4$ MeV]. The former facilitates the preservation of the ^{12}B polarization, the latter allows the discrimination of the ambient ("beam off") background. It is worthwhile to mention that the threshold of $^{12}\mathrm{C}(n,p)^{12}\mathrm{B}$ is at $E_n = 14.5$ MeV (see Fig. 1, taken from Ref. 2). This is an advantage in the sense that slow background

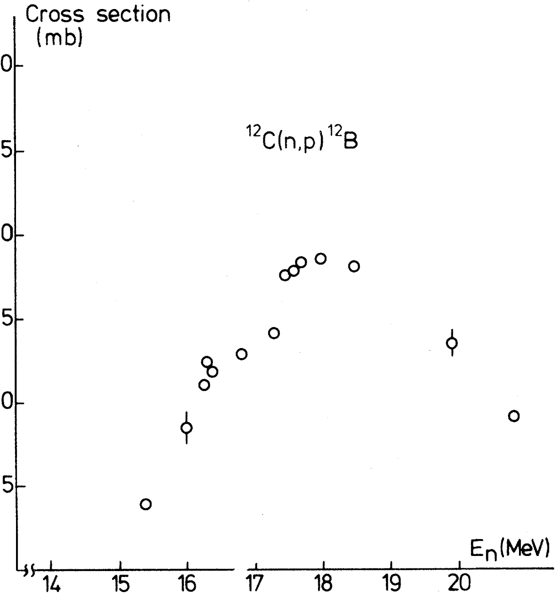

FIG. 1. Cross section of the $^{12}\mathrm{C}(n,p)^{12}\mathrm{B}$ activation reaction versus the neutron energy E_n (taken from Ref. 2).

neutrons do not activate the carbon target.

The main experimental problem is the preservation of the polarization of ^{12}B "implanted" into a carbon target. Fortunately, there already exists a large amount of data[3-6] on this point. Figure 2 summarizes the relevant information, obtained with polarized recoils produced in the reaction ^{11}B$(d,p)^{12}$B. One observes that:

(1) The polarization of ^{12}B implanted is partially preserved provided the target is placed in a "large" (≥ 1 kG) longitudinal magnetic "holding" field (B_0) during the implantation and β decay. Thus, graphite is a suitable target for our purpose. Polarization measured with it in a given field B_0 can be corrected for the incomplete retention using the data in Fig. 2. The retention at $B_0 = 2$ kG is about 70%; this was established by comparison with fcc metals (for more details see Ref. 5).

(2) ^{12}B nuclei lose their polarization in certain materials (e.g., teflon, CH$_2$) completely. A CH$_2$ target is used to detect possible instrumental asymmetries.

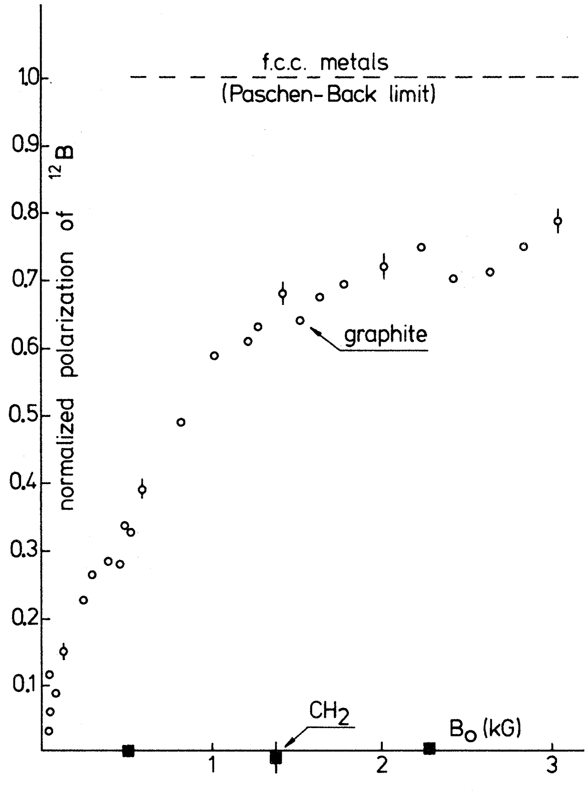

FIG. 2. Polarization of ^{12}B produced in ^{11}B$(d,p)^{12}$B after implantation in various materials versus the longitudinal decoupling field B_0 (from Refs. 5 and 6). For fcc metals the individual data points are not shown (see Ref. 5).

II. THE POLARIZED NEUTRON BEAM

Figure 3 is a scheme of the setup used in the production of polarized neutrons by the ^{2}H$(\alpha,\vec{n})\alpha p$ reaction. A deuterium gas target (5 atm pressure) is bombarded with a 40 MeV chopped (30 ms "on" and 60 ms "off") α beam from the cyclotron of the University of Louvain. Neutrons produced at 20° (in the laboratory) traverse a magnetic spin rotator (transverse field B_x) before hitting the carbon target (10×10 cm^2). The differential cross section of the ^{2}H$(\alpha,\vec{n})\alpha p$ reaction and the polarization of the neutrons, taken from Ref. 7, are shown in Fig. 4. Combining the data of Figs. 1 and 4, one sees that ^{12}B is produced with an average cross section of 5 mb at an average energy $\bar{E}_n = 18$ MeV. The neutron polarization is roughly constant, $P_n = -0.45$ (the negative sign means, following the Basel convention,[8] that the neutron spin is "up" in the laboratory) in the energy interval of interest.

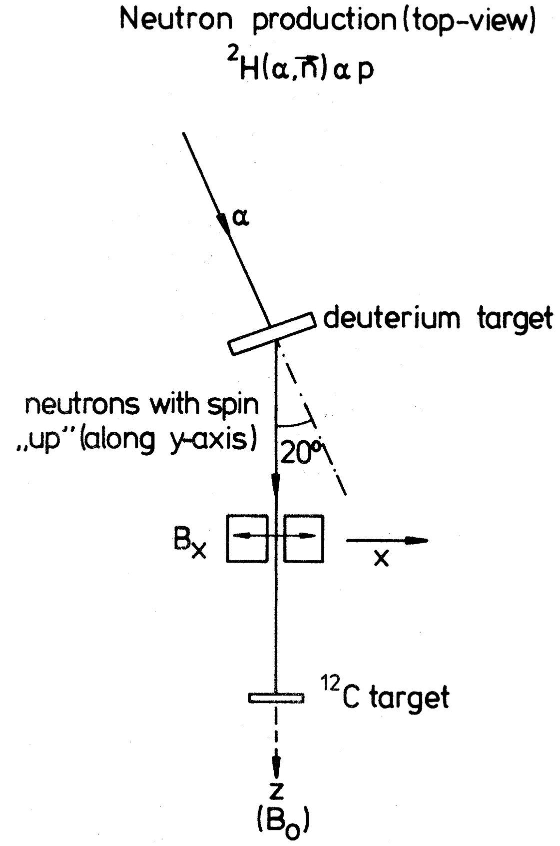

FIG. 3. A scheme of the setup for the production of polarized neutrons using the ^{2}H$(\alpha,\vec{n})\alpha p$ reaction.

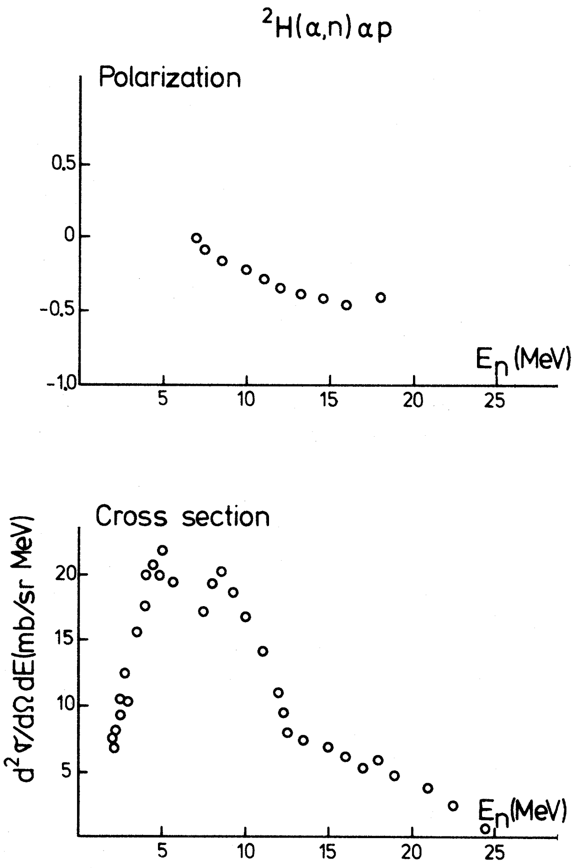

FIG. 4. Cross section of $^2H(\alpha,\vec{n})\alpha p$ (at 40 MeV alpha particle energy and at neutron angle 20°) and polarization of neutrons versus E_n (results taken from Ref. 7).

III. THE POLARIMETER

Figure 5 shows the apparatus for longitudinally polarized neutrons (moving along the z axis). It consists of:

—Helmholtz coils producing the decoupling field B_0 (2.0 kG).

—A target (graphite or CH_2) in which ^{12}B is produced and recoil implanted. Its thickness, 1.7 g/cm^2, is a compromise between the production rate of ^{12}B and the β-ray absorption.

—Two β-ray counter telescopes composed of plastic scintillators ($100\times100\times1$ mm^3). Quadruple coincidences, i.e., $123\bar{4}$ and $456\bar{1}$, count N_B and N_F (β rays emitted backward and forward). The coincidences are counted during the 60 ms neutron-beam off period following the 30 ms activation period.

The time distribution of N_B+N_F was measured with and without the graphite target. The difference (target in −target out) was found compatible with a decay curve of $\tau=(30\pm3)$ ms, i.e., the lifetime of ^{12}B.

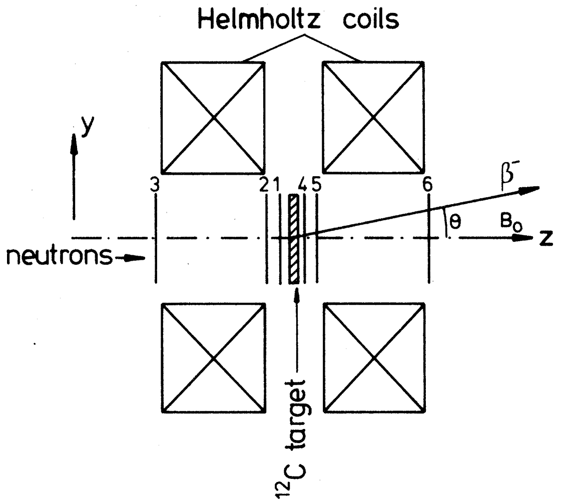

FIG. 5. Polarimeter for longitudinally polarized neutrons. Note that a Cu absorber of 1 g/cm^2 (not shown) was placed between counters 2 and 3 and also between 5 and 6 in order to attenuate the soft laboratory background.

The electron angular distribution in the $^{12}B\rightarrow{}^{12}C$ β decay is given as[9]

$$W(\theta)\sim(1-P_N\cos\theta)\ , \qquad (1)$$

where P_N is the projection of the ^{12}B polarization along $\vec{B}_0$ and θ is the angle between the latter and the β momentum. The beta-decay asymmetry A is determined from the ratio of counting rates N_B/N_F.

IV. DETERMINATION OF THE POLARIZATION TRANSFER EFFICIENCY $\epsilon=P_N/P_n$

Any desired longitudinal neutron polarization P_n could be obtained with the spin rotator; a rotation by +(−)90°, i.e., into the forward (backward) direction, required $B_x=+(-)9.0$ kG. The corresponding counting ratios $(N_B/N_F)_{+(-)}$ yield the decay asymmetry A, as defined

$$A=[(N_B/N_F)_+/(N_B/N_F)_-]-1\cong4\tilde{P}_N\ , \qquad (2)$$

where $\tilde{P}_N$ is the raw polarization (yet to be corrected for attenuations). Figure 6 shows A vs $|B_x|$. The fitted sine curve, proportional to P_n (calculated for monoenergetic neutrons of 18 MeV) reproduces the data well. The CH_2 point indicates that the in-

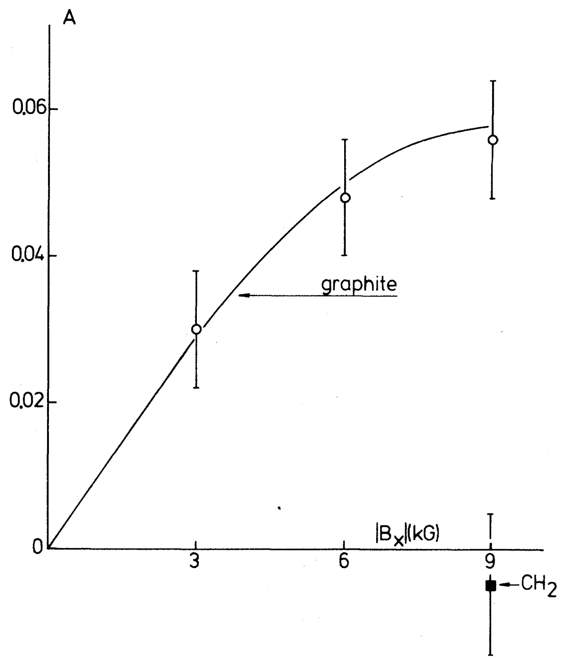

FIG. 6. Forward/backward beta-decay asymmetry [Eq. (2)] versus the neutron spin precessing field $|B_x|$. The sine curve fitted to the graphite points is proportional to the longitudinal component of the neutron polarization.

strumental asymmetry was compatible with zero. From the fit one obtains:

$$\tilde{P}_N = 0.0150 \pm 0.0015 \ . \tag{3}$$

This result has to be corrected for the attenuation (f) which is a product of four factors:

—f_a, owing to the background, determined by comparing the counting rates without and with the graphite target.

—f_b, owing to geometrical effects (finite solid angles, finite target dimensions), known from an earlier experiment performed under very similar conditions.[4–6]

TABLE I. Attenuations f_i affecting the beta-decay asymmetry.

f_i	Origin	Value
f_a	Background	0.70 ± 0.03
f_b	Finite size effects (target, counters)	0.68 ± 0.03
f_c	Spread of the Larmor angle	0.95 ± 0.02
f_d	Relaxation, parital decoupling	0.68 ± 0.02

—f_c, owing to the spread in the spin rotation angle induced by the spread in E_n (14.5–25 MeV).

—f_d, owing to the partial decoupling of the ^{12}B polarization (0.72, see Fig. 2), and to relaxation (0.95) (Ref. 6).

Table I summarizes these attenuation factors. The overall attenuation (equal for both telescopes) if $f = 0.31 \pm 0.02$, yielding the corrected result

$$P_N = 0.048 \pm 0.006 \ . \tag{4}$$

Comparing this with the initial neutron polarization,[7] one obtains the efficiency ϵ_L for the transfer of longitudinal neutron polarization to ^{12}B nuclei as

$$|\epsilon| = 0.11 \pm 0.02 \ . \tag{5}$$

CONCLUSION

The longitudinal polarization of fast neutrons is transferred to the product nucleus in $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}$. This observation might be exploited in two ways.

TABLE II. Merits of the "classical" n polarimeter and those of the polarimeter based on the $^{12}\mathrm{C}(\vec{n},p)^{12}\mathrm{B}$ activation reaction.

Parameters	Classical polarimeter (Ref. 10)	Activation reaction
Counting rate	Equivalent	
Measured polarization signal (100% n polarization)	0.9	0.1
Neutron energy	Differential	Integral
Beam intensity	Limited	Unlimited

On one hand, one can measure ϵ [in this or in other $(\vec{n},p)$ reactions] in order to test nuclear structure. On the other hand, one can exploit this observation to construct polarimeters. The advantage of a polarimeter based on an activation reaction is obvious; problems with the "in-beam" counting and the beam related background are avoided.

Table II compares the merits of the "classical" neutron polarimeter based on the left/right asymmetry in nucleon-nucleus scattering[10] with those of the polarimeter discussed here. The use of the latter, which is a very simple device, can be recommended when one deals with "very intense" pulsed beams.

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