PROTON-NEUTRON INTERACTION AND THE (p,n) REACTION IN MIRROR NUCLEI*

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(Received June 10, 1959)

Direct-interaction reactions have been treated by a number of authors[1] from the point of view of obtaining information concerning spins and parities of excited states of nuclei. The purpose of this note is to point out a new use of this type of reaction—a study of the direct interaction itself.

It should be emphasized that the direct interaction referred to is the effective neutron-proton potential within the nucleus. Recent theoretical studies indicate that this effective interaction is essentially the long-range part (distances $\gtrsim 10^{-13}$ cm) of the actual two-nucleon interaction.[2] The (p,n) reactions on mirror nuclei are a particularly promising source of information on this effective interaction, as will be developed below.

Consider as an example, the mirror nucleus reaction

$$C^{13}(p,n)N^{13} \tag{1}$$

going to the ground state.[3] [It can be shown that the (p,n) reaction is equivalent in the view adopted here for the two cases, doubly closed shells plus one neutron or minus one proton. For example, the ground-state reactions $C^{13}(p,n)N^{13}$ and $N^{15}(p,n)O^{15}$ should be twin reactions.[4]] In the j-j coupling shell model, the last neutron in C^{13} lies beyond doubly closed neutron and proton subshells.[5] The (p,n) reaction is regarded as involving only the neutron beyond the C^{12} core. The interaction between this extra-core neutron and the incident proton is written

$$\mathcal{V} = V_a + V_b P^\tau, \tag{2}$$

where V_a and V_b are in general spin-dependent central potentials and P^τ is the isotopic spin exchange operator. The antisymmetric wave functions for initial and final states appropriate to the reaction (1) are

$$|i\rangle = \frac{1}{\sqrt{2}}\{|1,2\rangle\pi(2)\nu(1) - |2,1\rangle\pi(1)\nu(2)\}, \tag{3}$$

$$|f\rangle = \frac{1}{\sqrt{2}}\{|1,2\rangle\pi(1)\nu(2) - |2,1\rangle\pi(2)\nu(1)\}, \tag{3'}$$

where $|1,2\rangle$ denotes a state with nucleon 1 bound by the C^{12} core, and nucleon 2 free, and π and ν are isotopic spin functions corresponding to proton and neutron states, respectively.

The matrix element of $\mathcal{V}$ taken between the initial and final states (3) and (3′) is

$$\langle f|\mathcal{V}|i\rangle = \langle 1,2|V_b|1,2\rangle - \langle 1,2|V_a|2,1\rangle. \tag{4}$$

Thus the matrix element of $\mathcal{V}$ separates into two parts, one of which is a "direct" matrix element, $\langle V_b\rangle$, and the other an "exchange" matrix element, $\langle V_a\rangle$. The "direct" matrix element refers to the charge exchange process in which the charge on the incident proton is transferred to the bound neutron. The "exchange" matrix element refers to the knock-out process in which the incident proton is captured, knocking out the extra-core neutron.

We may ignore the exchange integral in (4) compared to the direct integral because of the poor overlap of the bound and free states wave functions on the one hand and on the other hand, the good overlap of the extra-core neutron wave function in C^{13} with the extra-core proton wave function in N^{13}. It is emphasized that in mirror nuclei, this overlap argument should be particularly valid, because, aside from Coulomb distortion, the bound-state wave functions that enter the matrix elements are identical. Another way of looking at this is to realize that the direct integral refers to forward scattering, while the exchange integral refers to back scattering. We know that if the scattering of two particles interacting through a potential is calculated, say in Born approximation, the forward scattering (small momentum transfer) is much larger than the back scattering (large momentum transfer).

In the above approximation therefore, the (p,n) reaction connecting ground states of mirror nuclei singles out the isotopic spin exchange part, V_b, of the neutron-proton interaction inside nuclei. Thus a comparison of the experimental cross section for this reaction with a detailed theoretical calculation of the cross section ought to provide the potential V_b of (2). It is important to note that no one has yet succeeded in calculating the correct absolute magnitude of the cross section for a direct interaction process. Levinson and Banerjee[6] have given the most complete treatment in their study of proton inelastic scattering from C^{12}. They found it necessary to use a direct interaction with a strength of more than twice the free nucleon-nucleon potential. These authors suggested that the increased effective interaction may arise from a polarization of the nucleons in the target nucleus. This effect would of course be absent in the interaction (1), if it is correct to think of the target nucleus as an inert core plus one neutron in a well-defined state. Moreover the (p, n) reaction involves unambiguously a nucleon-nucleon interaction, whereas inelastic scattering by direct interaction may proceed by particle excitation in the target, or by excitation of a collective state, and these two modes are not necessarily easily distinguished.[7]

Thus the (p, n) reactions connecting the ground states of mirror nuclei are particularly suited to a rather direct measurement of the effective proton-neutron interaction in nuclei, or more specifically the charge exchange part of the interaction.

*This work was supported in part by the U. S. Atomic Energy Commission.

[1]Many references to the earlier work can be found in J. S. Blair and E. M. Henley, Phys. Rev. 112, 2029 (1958). See also N. K. Glendenning, Phys. Rev. (to be published).

[2]S. A. Moszkowski, Office of Ordnance Research Technical Report No. 2, University of California at Los Angeles, April, 1959 (unpublished).

[3]Recent measurements of the angular distribution of neutrons from this reaction are reported in S. D. Bloom and R. D. Albert, Bull. Am. Phys. Soc. 4, 321 (1959); see also Albert, Bloom, and Glendenning (to be published).

[4]This point as well as some others briefly referred to throughout this Letter are developed in detail in a University of California Radiation Laboratory Report now in preparation.

[5]Evidence strongly supporting the extreme j-j coupling shell model for this case is given in M. K. Banerjee and C. A. Levinson, Ann. Phys. 2, 499 (1957).

[6]C. A. Levinson and M. K. Banerjee, Ann. Phys. 2, 471 (1957); 2, 499 (1957); 3, 67 (1958).

[7]H. Ui, Progr. Theoret. Phys. (Kyoto) 18, 163 (1957); N. K. Glendenning, Ph.D. thesis, Indiana University, 1958 (unpublished).

ELECTROMAGNETIC CORRECTIONS TO THE B^{12}-N^{12} β-SPECTRUM RATIO*

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(Received June 19, 1959)

It has recently been suggested[1] that a precise comparison of the β spectra of B^{12} and N^{12} transitions to the ground state of C^{12} would provide a test of the nature of the vector interaction in β decay. Let the spectrum of each transition, divided by the corresponding Fermi spectrum, be called $S(E)$, where E is the total energy of the β ray. Then define

$$R(E) \equiv S(E, B^{12})/S(E, N^{12}). \qquad (1)$$

In reference 1 it was shown that the conserved vector current theory of β decay[2] predicts the result[3]

$$R(E) \approx \text{const}(1 + AE), \qquad (2)$$

where A is determined by the width of the 15.11-Mev level in C^{12} for γ transitions to the ground state and comes out

$$A = 1.33\,\% \pm 0.15\,\% \text{ per Mev}, \qquad (3)$$

using the measurements of Hayward and Fuller,[4] subsequently confirmed by Garwin.[5]

According to the more usual theory of β decay, in which the pion is not assigned any intrinsic β-decay "charge," we may expect a formula similar to (2), but with a much smaller value of A; the reduction factor in A should be roughly the factor by which $\mu_p - \mu_n$ is reduced if the pion current contributions to this quantity are omitted. (Here μ_p and μ_n are the proton and neutron magnetic moments.) A reasonable guess is that $\mu_p - \mu_n$ would become about one Bohr magneton