IC/88/175
INTERNAL REPORT
(Limited distribution)

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

SPIN OF TWO-NUCLEON SYSTEM AND NUCLEON-ANTINUCLEON COMBINATION IN THE S-STATE *

A.T. Baranik, A. El-Naghy
Physics Department, Faculty of Science, Cairo University, Cairo, Egypt

and

S. Ramadan **
International Centre for Theoretical Physics, Trieste, Italy.

ABSTRACT

The spin of the two nucleon combination was studied. It was found that the resultant combination could be treated as a boson with spin one or zero, and the spin one state is more stable than the spin zero state. In the case of nucleon-antinucleon combination the spin zero state is more stable than the spin one state. The approach succeeded in describing the general features of the nucleon-nucleon and nucleon antinucleon scattering and polarization.

MIRAMARE - TRIESTE
August 1988

* To be submitted for publication.

** On leave of absence from: Physics Department, Faculty of Science, Cairo University, Cairo, Egypt.

1. Introduction:

The two nucleon system has only one bound state, the deuteron, in which a proton and neutron are bound by 2.25 MeV in a spin one state, with zero orbital angular momentum between them. The absence of a bound state in the proton-proton system could be attributed to the electromagnetic effects, but such an explanation will not work for two neutrons. Although the proton-neutron system is found only in spin one state, low energy neutron-proton scattering data makes it clear that this two nucleon system exists in both spin one and zero states.

A wave function $\psi_1(r_1,t)$ and $\psi_2(r_2,t)$ of two nucleons [1,2] traveling in opposite directions could be represented as:

$$\psi_1(r_1,t) = \sin(k_1r_1-wt), \quad \psi_2(r_2,t) = \sin(k_2r_2+wt)$$

The space wave function of two nucleon system could be represented as :

$$\psi(r,t) = \psi_1(r_1,t)\ \psi_2(r_2,t)$$

The wave function could be written also as:

$$=\psi_1(r_1,t)\ \psi_2(r_2,t) - \psi_2(r_1,t)\ \psi_1(r_2,t)$$

in which the wave function is antisymmetric or

$$=\psi_1(r_1,t)\ \psi_2(r_2,t) + \psi_2(r_1,t)\ \psi_1(r_2,t)$$

and in this case the wave function is symmetric.

The wave function $\theta(r,t,s)$ could be written in a separable form:

$$\theta(r,t,s) = \psi(r,t)\,\phi(s)$$

$$\phi(s)=\phi(\uparrow) \quad \text{if} \quad \phi(+) = 1,\ \phi(-) = 0$$

$$\phi(x)=\phi(\downarrow) \quad \text{if} \quad \phi(+) = 0,\ \phi(-) = 1$$

where $\phi(\uparrow)$ is spin up and $\phi(\downarrow)$ is spin down, $\phi(\uparrow)$ and $\phi(\downarrow)$ could be represented in one column matrix

$$\phi(\uparrow) = \binom{1}{0} \quad , \qquad \phi(\downarrow) = \binom{0}{1}$$

The spin wave function of two nucleons could be written as

$$\phi_1(\uparrow) \quad \phi_2(\uparrow) \quad , \quad \phi_1(\downarrow) \quad \phi_2(\downarrow) \quad \text{or}$$

$$(1/\sqrt{2}) \{ \phi_1(\uparrow) \ \phi_2(\downarrow) + \phi_1 \phi_2(\uparrow) \}$$

which is symmetric, or the difference of products

$$(1/\sqrt{2}) \{ \phi_1(\uparrow) \phi_2(\downarrow) - \phi_1(\downarrow) \ \phi_2(\uparrow) \}$$

which is antisymmetric.

It can also be written as

$$\phi_1(R) \ \phi_2(R) \quad , \quad \phi_1(L) \ \phi_2(L)$$

or $(1/\sqrt{2})\{ \phi_1(R) \ \phi_2(L) + \phi_1(L) \ \phi_2(R) \}$

or $(1/\sqrt{2})\{ \phi_1(R) \ \phi_2(L) - \phi_1(L) \ \phi_2(R) \}$

where R and L are right handed and left handed respectively.

If we have

$\phi = \binom{c_1}{c_2}$ before rotation and

$\phi' = \binom{c'_1}{c'_2}$ after rotation

$$\phi\binom{c'_1}{c'_2} = u \ \binom{c_1}{c_2}$$

where u is matrix whose elements depend on the parameters of rotation only.

The direction of spin changes from right to left, or from left to right, by a torque and the torque acting on a body is

$$r F_\theta = -\partial V/\partial\theta$$

The potential V is a function of θ and not merely a function of r. This is a noncentral force, it is a tensor force.

The complete wave function describing the system will be the product of the space wave function and the spin wave function.

In accordance with Pauli exclusion principle, the wave function can be symmetric in spin wave function and antisymmetric in space coordinates, or it can be antisymmetric in spin wave function and symmetric in space coordinates. Only wave functions with even ℓ, S=0 or odd ℓ, S=1 satisfy the Pauli exclusion principle for identical nucleons. These states are the T=1 states, where T is the isobaric spin.

The states with even ℓ, S=1 odd ℓ, S=0 are the T=0 states. The T=0 states are available only to the neutron-proton system.

2. The representation of two nucleon combination:

As the non polarized nucleon can have spin + ½ and - ½, the probability distribution of the nucleon could be considered to propagate rotating once to the right and once to the left in a sine wave as represented in

Fig. (1a). The arrows in the figure represent the direction of rotation of the amplitude and it is taken in the upward direction of the paper. In case of antinucleon, as it has opposite magnetic moment (at the instant of nucleon-antincucleon pair creation), the direction of the arrows is taken in the backward direction of the paper Fig. (1b). The polarized nucleon and antinucleon are represented in Figs. (1c) and (1d) respectively and the direction of rotation is opposite to each other.

The four possible combinations of the nucleon-antinucleon and nucleon-nucleon are represnted in Fig. (2). Figure (2a) represents the nucleon-antinucleon with opposite direction of rotation of the arrows which will give spin zero state. The space wave function is symmetric and the spin wave function is antisymmetric.

Figure (2b) represents the nucleon-nucleon combination with spin one state which is also symmetric in space coordiantes and symmetric in spin wave function.

Figure (2c) represents the nucleon-antinucleon in spin one state and the space corrdinates are antisymmetric and symmetric in spin wave function.

Figure (2d) represents the nucleon-nucleon in spin zero and antisymmetric space coordinates and antisymmetric spin wave function.

The forces in the first case have opposite directions. This shows that this kind of interaction can appear in elastic scattering and a stable combination is probable.

In the second case the forces have the same direction and this is the case of neutron-proton system, and in this case a stable combination is more probable. The differential elastic cross section in the two cases will be characterized by a forward peak. However, in the second case a head on collision can occur and it will be characterized by a backward peak.

In the last two cases the antisymmetrical wave functions will vanish and exhibit a strong mutual repulsion which disturbs the scattering process. A stable combination is less probable in this two cases.

In the case of neutron-neutron and proton-proton combination, both particles have the same magnetic moment and they interact with both right handed screw or both with left handed screw which will prevent the interference of the two waves.

Figures (3a) and (3b) show the angular distributions for $\bar{P}P$ and nP scatterings respectively. Figure(4)represents the PP scattering. All distributions are characterized by forward peak. The distributions in Fig. (3b) exihibit forward and backward peaks at high energies. These features are in agreement with the given concepts.

According to present picture, the polarisation in PP scattering will be directed totally in one side. In case of np scattering, Figs.(2b) and(2d), the polarization of particles scattered in the forward direction will be opposite to those scattered in the backward direction. In the case of nucleon-antinucleon scattering the polarization is expected to be in one side for the forward scattered particles. The cross section for particles scattered in the backward direction is expected to be very weak (Figs (2a) and (2c)). Since the magnetic field of the interacting charged particles will increase with the velocity, the polarisation is expected to increase with the energy of the particles. The experimental data of ref. 3, confirm these predictions. Figures (2a) and (2d) represent spin zero state for nucleon-antinucleon and nucleon-nucleon interactions. The orientation of the arrows in the two cases are different. In the first case the interaction leads to spin zero decaying boson, while in the second case the result is two stable fermions in opposite direction. It is possible to reach the first orientation using polarized nucleons as projectile and/or, targets. If it is possible, it will show if the annihilation of nucleon anitnucleon is due to dynamical properties or related to internal properties. Stability of fermions (nucleons and electrons) are interpreted by the conservation of baryon and lepton number. Spin 1/2 for the two stable particles may raise a question about dynamical properties.

3. Conclusion:

The figure representation given in this paper can clarify the general features of the nucleon-nucleon

experiments. The representation of the space wave function with the spin wave function is simple and useful. Its use in both experiment and theory may help in planning experiments and using the suitable way for theoretical calculations.

ACKNOWLEDGMENTS

One of the authors (S.R.) would like to thank the Kuwait Foundation for Advancement of Sciences for financial support. He would also like to thank Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste.

REFERENCES

1. B.L. Cohen, Concepts of Nuclear Physics, McGraw-Hill Publishing Company (TMH Edition) 1971.
2. L.I. Schiff, Quantum Mechanics, McGraw-Hill Book Company (3rd. Editions), 1968.
3. R. Vinh Mau, Nucl. Phys. A374,3c-23c, 1982.

FIGURE CAPTIONS

Fig. (1a): The nucleon amplitude spining once to the right and once to the left in the direction of arrows.

(1b): The antinucleon amplitude spinning once to the right and once to the left in the direction of arrows.

(1c,1d): The polarized nucleon and antinucleon respectively.

Fig. (2a): The combined nucleon-antinucleon with spin zero.

(2b): The nucleon-nucleon combination with spin one.

(2c): The nucleon-antinucleon combination with spin one.

(2d): The nucleon-nucleon combination with spin zero.

Fig.(3): Results from nucleon-nucleon scattering experiments. Cross sections from (a) p-p and (b) n-p scattering at various angles for various incident energies (numbers attached to the curves, in MeV). (From M.J. Moravcsik, "The Two Nucleon Interaction", (Larendon Press, Oxford, 1963).

Fig. (4): The differential cross-section of scattered particles in $P\bar{P}$ collision at 226.4 MeV from ref.(3).

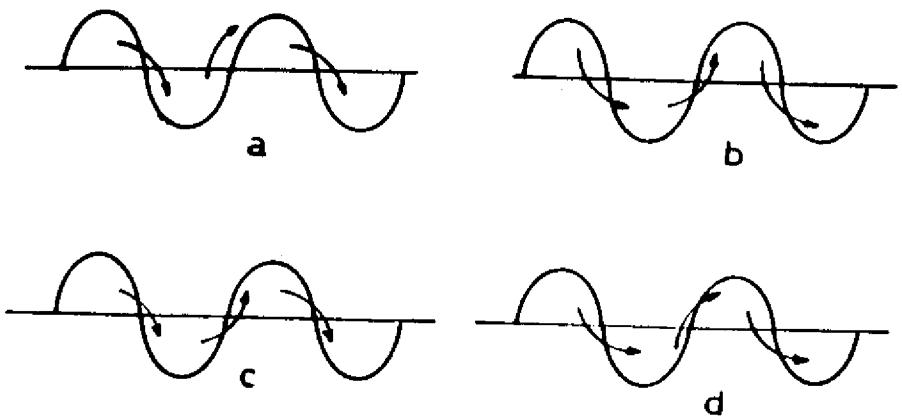


Fig.(1)

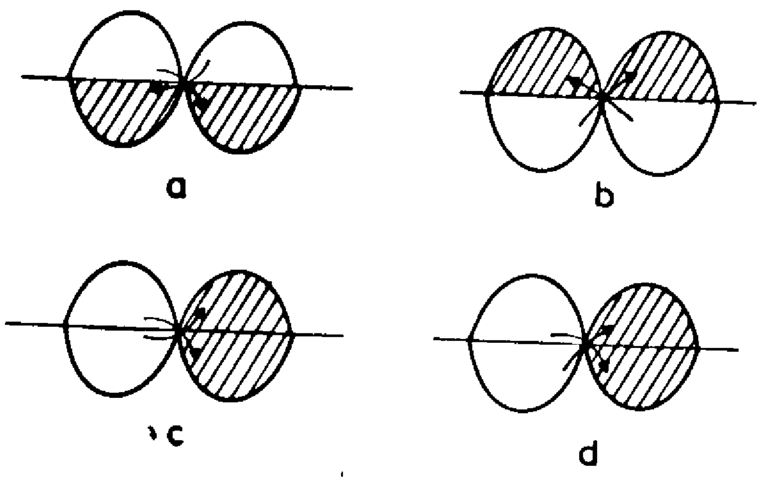


Fig.(2)

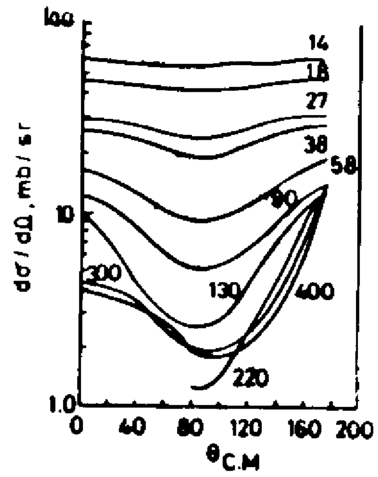


Fig.(3a)

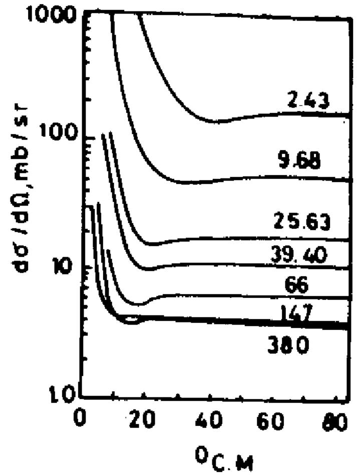
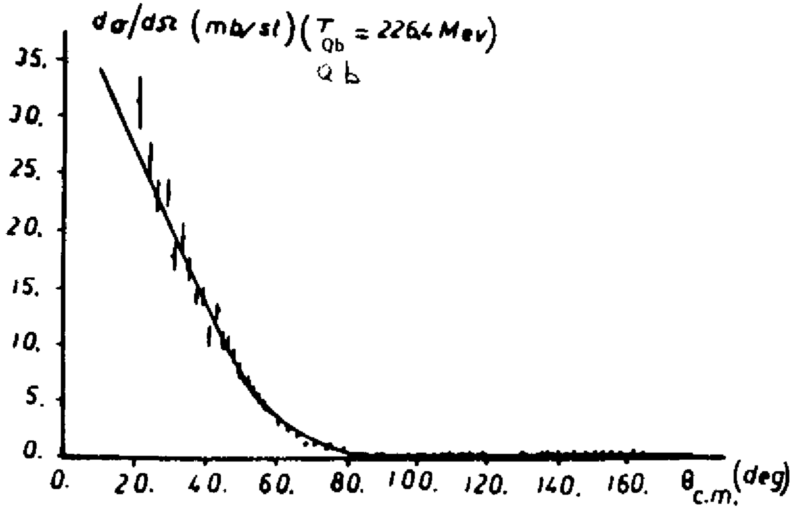


Fig.(3b)



Fig(4)