A NOTE ON CHARGE INDEPENDENCE AND NUCLEON-ANTINUCLEON INTERACTIONS

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1. INTRODUCTION

SINCE the advent of high energy accelerators, considerable data has been obtained on the following type of interactions:

$$N_1 + N_2 \rightarrow N_3 + N_4 + \pi \tag{1}$$

$$N_1 + \pi_1 \rightarrow N_2 + \pi_2 \tag{2}$$

where N_1, N_2, ... stand for nucleons and π, π_1, ... for charged and neutral π-mesons. More recently anti-nucleons have been produced in the laboratory (Segrè *et al.*, 1956).

It is unlikely that any consistent field theoretical calculation could be made at present with any chance of explaining the above reactions. Reaction (2) has been understood for low energies by the application of Chew's static theory. Nucleon-nucleon collision has not been studied except at threshold while nucleon antinucleon interaction has not yet received detailed attention. In view of the recent experiments on antinucleon production and also of Segré's experiments (1956) on proton antiproton scattering, it is considered worthwhile to draw some inferences on nucleon-antinucleon interactions on the basis of charge independence of nuclear forces.

2. WAVE FUNCTIONS IN ISOTOPIC SPIN SPACE

The antiparticles can be brought into the present framework of isotopic spin if we adopt the Gellman-Nishijima assignment (Gellman, 1953; Nakano and Nishijima, 1953) of isotopic spin. According to this scheme, the particle and antiparticle have opposite values of T_3 the z-component of isotopic spin T. At first sight it might appear that it is not possible to distinguish between two systems one of which consists of a particle and an antiparticle and the other, of two particles. However the introduction of B the baryon number

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and the consequent definition of Q (the total charge of the system in units of e) by

$$Q = \sum_i (T_{3i} + \tfrac{1}{2} B_i) \tag{3}$$

makes it trivial since, for the first system $B = 0$ while for the second $B = 2$. We shall confine ourselves to the case $B = 0$.

Since the nucleon-antinucleon system is a strongly interacting one, the total isotopic spin T as well as M_T the z-component of T have to be conserved in addition to the conservation of baryon number. We shall use the abbreviation a_{T, M_T} to denote the wave function of total isotopic spin T and z-component M_T. The dependence on B (in the present case $B = 0$) is implicit. We next observe that the isotopic spins of a group of particles can be added in exactly the same way as the addition of angular momenta (see Blatt and Weisskopf, 1954). Thus we have

$$\begin{aligned} a_{1,-1}(N\bar{N}) &= \bar{p}(1)\, n(2) \\ a_{1,0}(N\bar{N}) &= \frac{1}{\sqrt{2}}\{\bar{p}(1)\, p(2) + \bar{n}(1)\, n(2)\} \\ a_{1,1}(N\bar{N}) &= p(1)\, \bar{n}(2) \\ a_{0,0}(N\bar{N}) &= \frac{1}{\sqrt{2}}\{\bar{p}(1)\, p(2) - \bar{n}(1)\, n(2)\} \end{aligned} \tag{4}$$

where p and n denote the isotopic spin wave functions for the proton and the neutron respectively and a bar over any particle denotes the corresponding antiparticle.

Next we re-express the nucleon and antinucleon wave functions in the isotopic spin representation. This is done by inverting the set of equations (4):

$$\begin{aligned} \bar{p}(1)\, n(2) &= a_{1,-1} \\ p(1)\, \bar{n}(2) &= a_{1,1} \\ \bar{p}(1)\, p(2) &= \frac{(a_{0,0} + a_{1,0})}{\sqrt{2}} \\ \bar{n}(1)\, n(2) &= \frac{(a_{1,0} - a_{0,0})}{\sqrt{2}} \end{aligned} \tag{5}$$

Using the set of equations (5) we can deal with all types of interactions.

3. Nucleon Antinucleon Scattering

From (5) it is obvious that the scattering amplitude for each of the processes

$$\bar{p} + n \rightarrow \bar{p} + n \tag{6}$$

$$p + \bar{n} \rightarrow p + \bar{n} \tag{7}$$

is b (1), the reaction amplitude corresponding to T = 1.† To study the more interesting processes,

$$p + \bar{p} \rightarrow p + \bar{p} \tag{8}$$

$$p + \bar{p} \rightarrow n + \bar{n} \tag{9}$$

we analyse the incident wave function $\bar{p}p$ in terms of isotopic spins 1 and 0 as exhibited in equation (5) and re-express the isotopic spin amplitudes in terms of observable particles. Thus we arrive at the following results for direct and charge exchange scattering:

$$\text{ampl.}\ (\bar{p}p \rightarrow \bar{p}p) = \tfrac{1}{2}\{b\,(1) + b\,(0)\} \tag{10}$$

$$\text{ampl.}\ (\bar{p}p \rightarrow \bar{n}n) = \tfrac{1}{2}\{b\,(1) - b\,(0)\} \tag{11}$$

Hence the ratio of the scattering cross-sections is given by

$$\frac{\sigma\,(\bar{p}p \rightarrow \bar{p}p)}{\sigma\,(\bar{p}p \rightarrow \bar{n}n)} = \left(\frac{1+\alpha}{1-\alpha}\right)^2 \tag{12}$$

where α is the ratio $b\,(0)/\,b\,(1)$. Thus an experimental determination of the ratio of direct to charge exchange scattering fixes the value of α.

4. Production of Mesons in Nucleon-Antinucleon Annihilation

We shall confine ourselves to the production of mesons in proton antiproton annihilation since this can be more easily observed. Now we need the wave functions in isotopic spin space in terms of meson charge states. The wave functions corresponding to (1, 0) and (0, 0) states are given by

† We shall denote the reaction amplitudes corresponding to T = 1 and T = 0 by b (1) and b (0) respectively.

$$a_{1,0}(\pi\pi) = \frac{1}{\sqrt{2}}\{\pi^+(1)\,\pi^-(2) - \pi^-(1)\,\pi^+(2)\}$$

$$a_{0,0}(\pi\pi) = \frac{1}{\sqrt{3}}\{\pi^+(1)\,\pi^-(2) + \pi^-(1)\,\pi^+(2) - \pi^0(1)\,\pi^0(2)\} \tag{13}$$

These equations are obtained by the use of vector addition coefficients. The final state of the mesons produced by the annihilation of $\bar{p}p$ is

$$\frac{1}{\sqrt{2}}\{b(0)\,a_{0,0} + b(1)\,a_{1,0}\}$$

$$= \left\{\frac{b(0)}{\sqrt{6}} + \frac{b(1)}{2}\right\}\pi^+(1)\,\pi^-(2) + \left\{\frac{b(0)}{\sqrt{6}} - \frac{b(1)}{2}\right\}$$

$$\times\, \pi^-(1)\,\pi^+(2) - \frac{b(0)}{\sqrt{6}}\,\pi^0(1)\,\pi^0(2) \tag{14}$$

Thus we obtain the following result for charged and neutral production:

$$\sigma = \sigma(\pi^+\pi^-)\left\{\frac{[b(1)]^2}{2} + \frac{[b(0)]^2}{3}\right\} + \sigma(\pi^0\pi^0)\,\frac{[b(0)]^2}{6} \tag{15}$$

The ratio of charged to neutral production is therefore

$$2 + \frac{3}{\alpha^2}.$$

If α is determined from scattering experiments, this result serves as a test for the hypothesis of charge independence. From (15) it follows that if $T = 1$ state predominates, charged production predominates while prodominance of $T = 0$ state leads to charged and neutral production equally.

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