ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E-2259

ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

S.M.Bilenky, R.M.Ryndin

DETERMINATION OF PARITY IN REACTIONS INDUCED BY GAMMA QUANTA

ЯФ, 1966, т 3, вып 2, стр. 332-335.

1965

E-2259

S.M.Bilenky, R.M.Ryndin

DETERMINATION OF PARITY IN REACTIONS INDUCED BY GAMMA QUANTA

Submitted to Jadernaja Fisika

1. In view of a fast increasing number of "elementary" particles experiments on the determination of intrinsic parities still remains an important problem of high-energy physics. At present experimenters have at their disposal rather intensive beams of gamma quanta. In this connection it is interesting to consider methods of the determination of the intrinsic parities in reactions of the type

$$\gamma + a \to b + c \ . \qquad (1)$$

The suggested methods are based only on the requirements of invariance under reflections in the reaction plane[1].

To indicate the basic states of the photon polarization[x)] we choose two real mutually orthogonal unit vectors $\vec{e}_1$ and $\vec{e}_2$ in the plane perpendicular to the photon momentum, the vector $\vec{e}_1$ being assumed to be parallel to the normal to the reaction plane. The amplitude of the reaction (1), if the photon polarization is $\vec{e}_r$ $(r = 1, 2)$, is written in the form: $\vec{e}_r \cdot \vec{M}_{\sigma_b \sigma_c, \sigma_a}(\vec{p}', \vec{p}) = [M(\vec{p}', \vec{p})]_{\sigma_b \sigma_c, \sigma_a r}$. Here $\vec{p}$ and $\vec{p}'$ are the initial and final momenta in the c.m.s. and σ_a, σ_b, σ_c are the spin variables of the particles. The state of the polarization of the photon is described by the density matrix $\rho = ½(1 + \vec{\xi} \cdot \vec{r})$, where r_i are Pauli matrices and ξ_i are Stokes parameters[2]. In the chosen basis ξ_2 indicates the degree of circular polarization, ξ_1 and ξ_3 are related to linear polarization.

From the invariance under reflections in the reaction plane we get[3]:

$$I R_b^{-1} R_c^{-1} M(\vec{p}', \vec{p}) R_a R_\gamma = M(\vec{p}', \vec{p}) \ . \qquad (2)$$

---

x) As the polarization direction we take the direction of the electric field.

Here $I = -\frac{I_a}{I_b I_c}$, I_a, I_b, I_c are the intrinsic parities of particles a, b and c, $R_a = \exp i \pi \vec{s}_a \cdot \vec{n}$ is the spin rotation operator of the particle a at the angle π around the normal $\vec{n} = \frac{\vec{p} \times \vec{p}'}{|\vec{p} \times \vec{p}'|}$, R_γ is the rotation operator for a photon and so on. It is easily seen that in the chosen basis $R_\gamma = r_3$. We emphasize that the transformation of the reflection (2) in the reaction plane is the only transformation which contains the relative parity and does not change the arguments of the reaction matrix. Consequently, all the relations between experimentally measurable quantities containnig I follow from (2). Eq. (2) shows also which information on the state of particle polarization should be used to determine I.

2. We first consider the reaction $\gamma + \frac{1}{2} \to 0 + \frac{1}{2}$ where 0 and 1/2 are the particle spins. Some problems of parity determination in such reactions have been discussed in refs[4-6]. For spin 1/2 the rotation operator at the angle π around the normal is $i\vec{\sigma} \cdot \vec{n}$ and the condition (2) in the case under consideration reads

$$I \vec{\sigma} \cdot \vec{n} M(\vec{p}', \vec{p}) \vec{\sigma} \cdot \vec{n} r_3 = M(\vec{p}', \vec{p}) . \tag{3}$$

In what follows we shall consider experiments with linearly polarized beams of gamma quanta.

The cross section for any reaction of the type (1) in the case of a linearly polarized beam and an unpolarized target is

$$\sigma = \sigma_0 \left(1 - P_\gamma \cos 2\phi \; \frac{Sp\, M\, r_3\, M^+}{Sp\, M\, M^+}\right) . \tag{4}$$

Here σ_0 is the cross section for the reaction with an unpolarized beam and an unpolarized target (P_γ is the degree of linear polarization and ϕ is the angle between the reaction plane and the plane of linear polarization). Hence, for the asymmetry we get

$$A = \frac{\sigma^{\perp} - \sigma^{\parallel}}{\sigma^{\perp} + \sigma^{\parallel}} = P_\gamma \frac{Sp\, M\, r_3\, M^+}{Sp\, M\, M^+} . \tag{5}$$

Here $\sigma^{\perp}$ and $\sigma^{\parallel}$ are the reaction cross sections for $\phi = \pi/2$ and $\phi = 0$ (the gamma-quantum polarization vector is perpendicular to the reaction plane or lies in it). Using (3), it may be easily seen that the coefficient for P_γ in (5) is ID where $D = \frac{Sp\, \vec{\sigma} \cdot \vec{n} M \vec{\sigma} \cdot \vec{n} M^+}{Sp\, M\, M^+}$ is the depolarization parameter in the reaction with unpolarized gamma quanta. To determine it, polarized target experiments are needed. If the target polarization $\vec{P}$ is directed along the normal ($\vec{P} = P\vec{n}$) then (5) can be rewritten in the form:

$$A = IP_{\gamma} D = I \frac{P_{\gamma}}{P} \frac{\langle\vec{\sigma}\cdot\vec{n}\rangle_{\vec{P}}\, \sigma_{\vec{P}} - \langle\vec{\sigma}\cdot\vec{n}\rangle_{-\vec{P}}\, \sigma_{-\vec{P}}}{\sigma_{\vec{P}} + \sigma_{-\vec{P}}} \qquad (6)$$

Here $\langle\vec{\sigma}\cdot\vec{n}\rangle_{\vec{P}} = 1/\sigma_{\vec{P}}\ \mathrm{Sp}\ \vec{\sigma}\cdot\vec{n} M \tfrac{1}{4}(1 + \vec{\sigma}\cdot\vec{P}) M^{+}$

is the polarization of the final fermion arising in the reaction with an unpolarized target and $\sigma_{\vec{P}}$ is the reaction cross section in this case. Eq. (6) contains parity and experimentally measured quantities. Thus to determine I two experiments should be performed. In the first experiment one measures the asymmetry with a linearly polarized gamma beam and an unpolarized target. In the second one the polarization of recoil particles in the case of unpolarized gamma quanta and a polarized target should be measured. With the aid of (3) it is easy to get some other relations among observables allowing to determine parity.

3. We consider reactions $\gamma + 0 \to 0 + s$. The operator of spin rotation at the angle π around $\vec{n}$ for a s spin boson can be expanded[3] in a complete set of spin-tensors T^{JM}:

$$R_{s} = \sum_{J\ \mathrm{even}} a^{J}(s)\, T^{J0} . \qquad (7)$$

The experissions for the coefficients $a^{J}(s)$ are given in ref[3] (the quantization axis in (7) is directed along the normal). From (2) we get, e.g. the following relation among observables:

$$A = \frac{\sigma^{\perp} - \sigma^{\parallel}}{\sigma^{\perp} + \sigma^{\parallel}} = I \sum_{J\ \mathrm{even}} a^{J}(s) \langle T^{J0}\rangle_{0} , \qquad (8)$$

where A is the asymmetry in the reaction with polarized gamma quanta, and $\langle T^{J0}\rangle_{0} = \dfrac{\mathrm{Sp}\ T^{J0} M M^{+}}{\mathrm{Sp}\ M M^{+}}$ is the average value of the operator T^{J0} in the reaction with an unpolarized beam.

4. We give the simplest relations which allow one to determine the relative parity in studying polarization effects in reactions such as $\gamma + \tfrac{1}{2} \to 0 + s$. From (2) it follows

$$A = \frac{\sigma^{\perp} - \sigma^{\parallel}}{\sigma^{\perp} + \sigma^{\parallel}} = I \frac{P_{\gamma}}{P} \frac{\sum_{J\ \mathrm{odd}} (-i) [\langle T^{J0}\rangle_{\vec{P}}\, \sigma_{\vec{P}} - \langle T^{J0}\rangle_{-\vec{P}}\, \sigma_{-\vec{P}}]}{\sigma_{\vec{P}} + \sigma_{-\vec{P}}} \qquad (9)$$

where $\langle T^{J0} \rangle_{\vec{P}}$ is the average value of T^{J0} in the reaction with an unpolarized beam and a polarized target. In an analogous way we find

$$\frac{\sigma^{\perp}_{\vec{P}} - \sigma^{\parallel}_{\vec{P}} - \sigma^{\perp}_{-\vec{P}} + \sigma^{\parallel}_{-\vec{P}}}{\sigma^{\perp}_{\vec{P}} + \sigma^{\parallel}_{\vec{P}} + \sigma^{\perp}_{-\vec{P}} + \sigma^{\perp}_{-\vec{P}}} = I \sum_{J\,odd} (-i) a^{J}(s) \langle T^{J0} \rangle_{0} P_{\gamma} P \; . \qquad (9a)$$

Here $\langle T^{J0} \rangle_0$ is the average value of T^{J0} in the reaction with an unpolarized beam and an unpolarized target, and $\sigma^{\perp}_{\vec{P}}$ and $\sigma^{\parallel}_{\vec{P}}$ are the cross sections for the process in the case of a polarized target and a linearly polarized gamma beam.

5. In conclusion we make some remarks. The first of them concerns the procedure of the determination of the average values $\langle T^{J0} \rangle$. In the case of a half-integer spin (Sections 2 and 4) $\langle T^{J0} \rangle$ can be determined from the angular distribution of the decay products if particles of spin s decay with non-conservation of parity, according to the scheme $s \to \frac{1}{2} + 0$ [7]. In the case of integer spin $\langle T^{J0} \rangle$ can be also determined from the angular distribution of the decay products if a particle of spin s decays according to the scheme $s \to 0 + 0$ (with conservation or non-conservation of parity) or $s \to 0 + \gamma$.

The second remark is related to experiments with completely linearly polarized beams. Note first of all that completely linearly polarized photons with electric (magnetic) vector parallel to the normal are described by the eigenstate of the rotation operator R_{γ} corresponding to the eigenvalue $+1(-1)$. Hence, it follows that for such photons the operator R_{γ} in (2) can be replaced by $+1$ (-1) and the condition (2) takes the form of the invariance conditions under the reflection in the reaction plane for the reaction $0 + a \to b + c$ which differs from (1) by the replacement of a gamma quantum by a boson of spin 0. Consequently, experiments which should be made to determine parity in reaction (1) with a completely polarized gamma beam the polarization of which is orthogonal to the reaction plane (lies in it), are identical to the corresponding experiments for the reaction $0 + a \to b + c$ [5,6]. In particular, in the reaction $\gamma + 0 \to 0 + s$ for the determination of parity and spin the maximum complexity method suggested in ref[8], can be employed.

Finally the obtained relations can be used, in principle, for the determination of the degree of linear polarization of gamma quanta. For example, eq. (6) means that the analysing power of the reaction is ID and, consequently, it can be determined in the reaction with an unpolarized gamma quantum beam and a polarized target. For this purpose it is convenient to use reactions such as $\gamma + p \to \Lambda + K^{+}$.

The authors are grateful to L.I.Lapidus and Ya.A.Smorodinsky for useful discussions.

References

1. A.Bohr. Nucl.Phys. 10, 486 (1959).
2. А.И.Ахиезер, В.Б.Берестецкий. Квантовая электродинамика, Москва, 1959.
3. S.M.Bilenky, R.M.Ryndin. Phys.Letters, 13, 159 (1964).
4. M.J.Moravcsik. Phys. Rev., 125, 1088 (1962).
5. M.Kawaguchi. Nuovo Cimento, 34, 1114 (1964).
6. P.L.Csonka, M.J.Moravcsik, M.D.Scadron. Phys.Letters, 15, 353 (1965).
7. N.Byers, S.Fenster. Phys. Rev. Letters, 11, 52 (1963).
8. M.Peshkin. Phys. Rev., 133, B428 (1964).

Received by Publising Department
on July 8, 1965.