THE "COMPLETE EXPERIMENT" IN β DECAY

Ya. A. SMORODINSKIĬ

Joint Institute of Nuclear Studies

Submitted to JETP editor February 17, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1606-1608 (May, 1959)

In an earlier paper[1] Puzikov, Ryndin, and the writer determined how many experiments are required for the reconstruction of the scattering matrix for scattering of nucleons by nucleons (the "complete experiment"). The results of that paper have been extended to the case of arbitrary spins of the colliding particles,[2] and also to the case of inelastic processes.[3] The analogous problem can also be solved for β decay.

Here we shall consider only the decay of the neutron. If the chirality of the leptons is conserved, the β-decay interaction Hamiltonian can be written in the form

$$H_\beta = (V_\alpha + A_\alpha)\langle e|\gamma_\alpha(1+\gamma_5)|\nu\rangle,$$

where V_α and A_α are the nucleon "currents" corresponding to the vector and axial-vector interactions, respectively. If we require that the neutron and the antiproton (which have the same isotopic-spin component) decay in identical ways, then it can be shown (cf. reference 4) that

$$V_\alpha = \langle p|a(k)\gamma_\alpha + b(k)\sigma_{\alpha\beta}k_\beta|n\rangle, \qquad (2)$$

$$A_\alpha = \langle p|c(k)\gamma_5\gamma_\alpha + d(k)\gamma_5 k_\alpha|n\rangle; \qquad (3)$$

$\sigma_{\alpha\beta} = i(\gamma_\alpha\gamma_\beta - \gamma_\beta\gamma_\alpha)/2$. Here $\langle p|$ and $|n\rangle$ are the wave functions of the free nucleons, and k is the four-vector momentum transfer (the sum of the momenta of the electron and antineutrino). It can be seen from this that all the properties of the β decay of the neutron are described by the four functions $a(k)$, $b(k)$, ... Furthermore the coefficient $b(k)$ describes what Gell-Mann[5] has called "weak magnetism". Ordinarily in the allowed approximation k is taken to be zero, and two constants, $a(0) = g_F$ and $c(0) = c_{GT}$ are measured. In principle, more precise measurements can also give the dependence of these coefficients on k. Since, however, the "dimensions" of the nucleon are $\sim \hbar/Mc$, and the maximum k is $\sim \hbar/mc$, the departure from the "allowed" approximation will be of the order of $m/M \sim 0.1$ percent. In such experiments we get the values of the form factors in a range of values of k determined by the decay energy. Measurements of these coefficients over a wider range of energies will be possible when it is possible to study the capture of antineutrinos of various energies by protons.

In this case four experiments must be made for each value of the momentum transfer (or for each value of the total momentum of the leptons in the β decay). The situation is simplified if we take into account a theorem of Gell-Mann,[5,6] from which it follows that for light nuclei the form factors $a(k)$ and $b(k)$ are the same as those that determine the scattering of electrons by protons and neutrons. Therefore if we use the data on the scattering of electrons there remain to be determined for β decay only two form factors, i.e., two experiments must be performed for each value of the momentum transfer.

It is obvious that what has been said remains valid also for any β decay between nuclei with spin $\frac{1}{2}$. If however, charge invariance is violated (non-mirror transitions), the number of form factors for each of the currents is increased by unity.

We shall also formulate the result for the general case of a transition between mirror nuclei.

If we consider the transition $I' \rightarrow I''$ (no), the number of form factors in the vector current is $2I + 1$, where I is the smaller of the spins I', I''. For light nuclei these form factors are determined from inelastic scattering of electrons with transition of the nucleus to the state isotopically similar to the final state in the β transition. The number of form factors in the axial-vector current is $2I$. In the case of the transition $I \rightarrow I'$ (yes) the numbers of form factors for the two currents are $2I$ and $2I + 1$. These same numbers determine the number of experiments that make up a complete experiment.

In this way the study of "forbidden" approximations and forbidden β transitions determines a set of form factors. Usually forbidden transitions are described in the literature by a set of nuclear matrix elements; in reality this is only an approximate way of specifying the form factors.* Simple, but rather cumbersome calculations make it possible to express the results of the various experiments in terms of the form factors. The formulas in question will be given in a later communication devoted to the general properties of β-decay form factors.

These same considerations are also valid for the capture of mesons. At least for light nuclei it can be expected that the form factors of the vector current will be the same as for electrons (for corresponding values of k). In the case of the axial-vector current there are indications that the β and μ form factors are different.[7] This fact makes experiments with μ mesons even more interesting.

The writer is grateful to R. Ryndin and S. Bilen'kiĭ for a helpful discussion of the results.

*We note that the form factors describe "collective" transitions which, for example, can make an important contribution in transitions of extended nuclei with large quadrupole moments.

[1] Puzikov, Ryndin, and Smorodinskiĭ, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 592 (1957), Soviet Phys. JETP **5**, 489 (1957).

[2] Bilen'kiĭ, Lapidus, Puzikov, and Ryndin, J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 959 (1958), Soviet Phys. JETP **8**, 669 (1959).

[3] L. D. Puzikov, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 947 (1958), Soviet Phys. JETP **7**, 655 (1958).

[4] M. L. Goldberger and S. B. Treiman, Phys. Rev. **111**, 354 (1958).

[5] M. Gell-Mann, Phys. Rev. **111**, 362 (1958).

[6] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).

[7] Burgman, Fischer, Leontic, Lundby, Meunier, Stroot, and Teja, Phys. Rev. Lett. **1**, 469 (1958).

Translated by W. H. Furry
333

ANGULAR ANISOTROPY AND ENERGY CHARACTERISTICS OF THE FISSION PROCESS

A. N. PROTOPOPOV, I. A. BARANOV, and V. P. ÉĬSMONT

Submitted to JETP editor February 27, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1608-1609 (May, 1959)

EXPERIMENTAL and theoretical investigations of the angular anisotropy of the fission of heavy nuclei, conducted so far, did not consider directly the problem of energy yield. Nevertheless, from the concepts developed up to now, one can expect that certain energy characteristics of the fission process will depend on the angle between the direction of incidence of the exciting particle and of the emitted fragments. For instance, it has been shown recently[1,2] that the degree of anisotropy in fission is strongly related to the effective temperature of the nucleus in the saddle point: the more electrons are evaporated up to the moment of attaining the critical deformation, the bigger is the anisotropy. We are, of course, considering fission of nuclei for sufficiently high excitation where the emission of nucleons before fission is energetically possible. One can then observe both cases of fission, with and without previous emission. The degree of anisotropy of the latter will be different. On the average, therefore, the number of neutrons in nuclei undergoing fission, as well as the energy of excitation, will be different for fission at an angle of 0° and 90° to the beam of incident particles. Consequently, one can expect certain differences in the kinetic energy of fragments emitted at different angles.

As an attempt to examine the relations mentioned above, the fission of U^{238} induced by neutrons with energy 14.9 Mev was studied. The energy of the additional fragments in fission along the direction of the neutron beam (0°) and in fission in the perpendicular direction to the beam (90°) was studied by means of a double ionization chamber. The angle of distribution was such that the emission direction of a fragment did not deviate by more than 26° from a given direction at 0° or 90°. Other conditions of the experiment were identical with those described earlier.[3] A total of 5000 fission events at the angle of 0° and 4000 events at the angle of 90° were recorded in alternating measurements.

It was found that, for a ratio of the fragment masses equal to 1.40 — 1.44 (close to the most probable value), the average kinetic energy of the fragments is equal to 170.8 ± 0.6 Mev at the angle of 0° and 169.4 ± 0.8 Mev at an angle of 90° (the indicated errors represent the average deviation of the results of separate series of measurements). The difference of the energy of fragments, if such exists, is therefore not bigger than 1.5%.

[1] I. Gal'pern and V. M. Strutinskiĭ, Paper presented at the Second International Conference on Peaceful Applications of Atomic Energy, Geneva, 1959.

[2] A. N. Protopopov, and V. P. Éĭsmont, J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1573 (1959), Soviet Phys. JETP, this issue, p. 1116.

[3] A. N. Protopopov and V. P. Éĭsmont, Атомная энергия (Atomic Energy), in press.

Translated by H. Kasha
334